

# Corrosion

## IN THIS ISSUE:

- Chlorinated Polyether Coatings  
From Water Suspension Systems . . . 32**
- Half of Space Sold for 1962  
Kansas City Corrosion Show . . . . . 59**
- Schedule of Events for Miami  
Southeast Region Conference . . . . . 61**
- Detection of Interference Current  
on Simulated Pipeline . . . . . 79**
- Sulfide Stress Cracking of Steels  
for N-80 Tubular Products . . . . . 81**
- Testing Construction Materials  
for Chemical Plant Waste Systems . . . 91**
- Aluminum Used for Portable  
Sea Water Distillation Equipment . . . 98**
- Leakage Conductance Coatings Surveys  
of Asphalt Mastic Coatings . . . . . 101**
- How Hardener Composition Affects  
Chemical Resistance of Epoxy Resins . 104**
- Electrochemical Approach to  
Prevention of Cavitation Damage . . 107**
- Low Potential Zinc Anode  
in Theory and Application . . . . . 122**



Complete Contents on Pages 4 and 5



# THE SURPRISING ECONOMICS OF BONDSTRAND®

...the pipe designed for corrosive chemicals



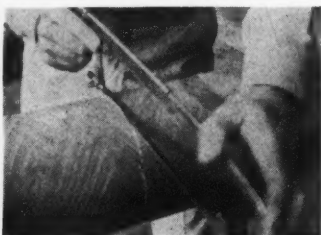
**STEEL**  
A 20' length of 6" schedule 40 carbon steel pipe weighs 398 lbs. Crane required for lifting.



**BONDSTRAND**  
A 20' length of 6" Bondstrand pipe weighs only 60 pounds. One man can lift and carry.



Cutting steel pipe takes four (or more) times longer than Bondstrand.



Bondstrand is cut with ordinary hacksaw. Preheating not required.



Two men required to bevel, clean, position, center and level a 90° elbow before welding.



Only one man required to apply adhesive and position a 90° Bondstrand elbow. It aligns itself.



Welder and helper required to tack weld, check alignment, make stringer weld and grind, make flush weld and grind again, make cover weld, grind and wire brush.



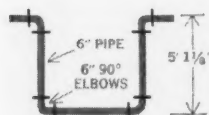
One man with a hammer and a two-by-four makes the Bondstrand Quick-Lock joint in a matter of seconds. Important: Bondstrand pipe may be handled immediately; no waiting for adhesive to cure.

IT TOOK 65 MINUTES TO WELD ONE ELBOW TO STEEL PIPE. ONE MAN MADE THE SAME ASSEMBLY WITH BONDSTRAND IN ONLY 10 MINUTES!

BONDSTRAND, the fiber glass reinforced epoxy pipe, handles nearly every corrosive solution—acids, salts, alkalis—used in industry today. It will withstand pressures up to 550 psi and temperatures up to 300°F. So will the complete line of BONDSTRAND fittings, 2" through 12".

The smooth, abrasion-resistant inner surface permanently retains its excellent flow characteristics (Hazen-Williams formula  $C=150$ ) and thus often permits use of one-size-smaller diameter pipe. BONDSTRAND is only one-eighth the weight of steel and because it resists exterior as well as interior corrosion it does not require continual maintenance painting.

BONDSTRAND versatility is unmatched by any other pipe—metallic, thermoplastic, glass or lined. What does this superiority cost? Less than you may suspect. Here is how BONDSTRAND compares with carbon steel in this simple pipe layout:



**TOTAL COST OF MATERIAL AND LABOR**

Schedule 40 Carbon Steel Pipe With Welding Elbows .....	<b>\$225.63</b>
Series 4000 Bondstrand Pipe With Bondstrand Elbows .....	<b>\$287.40</b>

Figures shown are from a strict time-and-cost study conducted by one of Southern California's leading independent piping and engineering firms.

This means that in this layout you get all the advantages of BONDSTRAND for only 21.7% more than ordinary carbon steel pipe. (In complex process piping, BONDSTRAND can actually cost less.) In Schedule 40 stainless steel, which approximates BONDSTRAND's chemical resistance, the layout would cost \$1,287.50—348% more than BONDSTRAND!

To evaluate the superiority of BONDSTRAND pipe for your specific requirements, write for complete technical data.



Dept. GW, 4809 Firestone Blvd., South Gate, California

921 Pitner Ave.  
Evanston, Ill.

360 Carnegie Ave.  
Kenilworth, N. J.

111 Colgate Ave.  
Buffalo, N. Y.

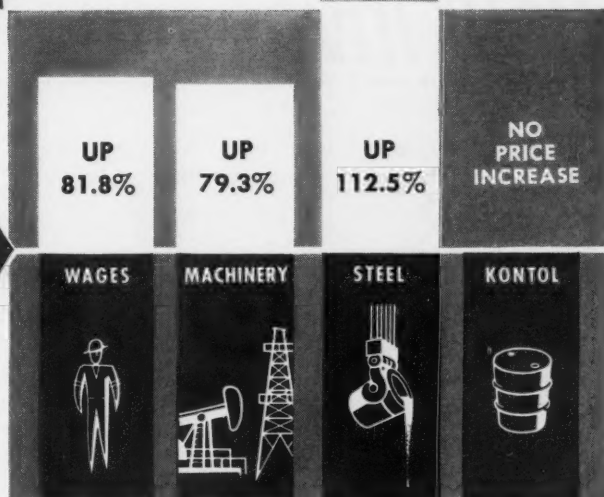
2404 Dennis St.  
Jacksonville, Fla.

6530 Supply Row  
Houston, Tex.



# another TRETOLITE SERVICE report

1948 COST LEVEL



IN A PERIOD OF  
RISING PRODUCTION COSTS

**KONTOL** *prices*  
*are still at 1948 level!*

The Tretolite research staff constantly seeks ways to produce better KONTOL\* Corrosion Inhibitor formulas for less money. This concern for *cost control* as well as *corrosion control* has kept the per gallon price of KONTOL at the 1948 level! Today, when costs of equipment, material, and wages are spiraling higher, it makes more sense than ever before to invest in a sound KONTOL corrosion control program.

*Ask the Man in the Red Car  
how it can be done.*



\*Registered trademark, Petrolite Corporation

**PETROLITE  
CORPORATION**

**TRETOLITE COMPANY**  
DIVISIONS

360 Marshall Avenue, Saint Louis 8, Missouri  
300 South Bascom Street, San Francisco, California

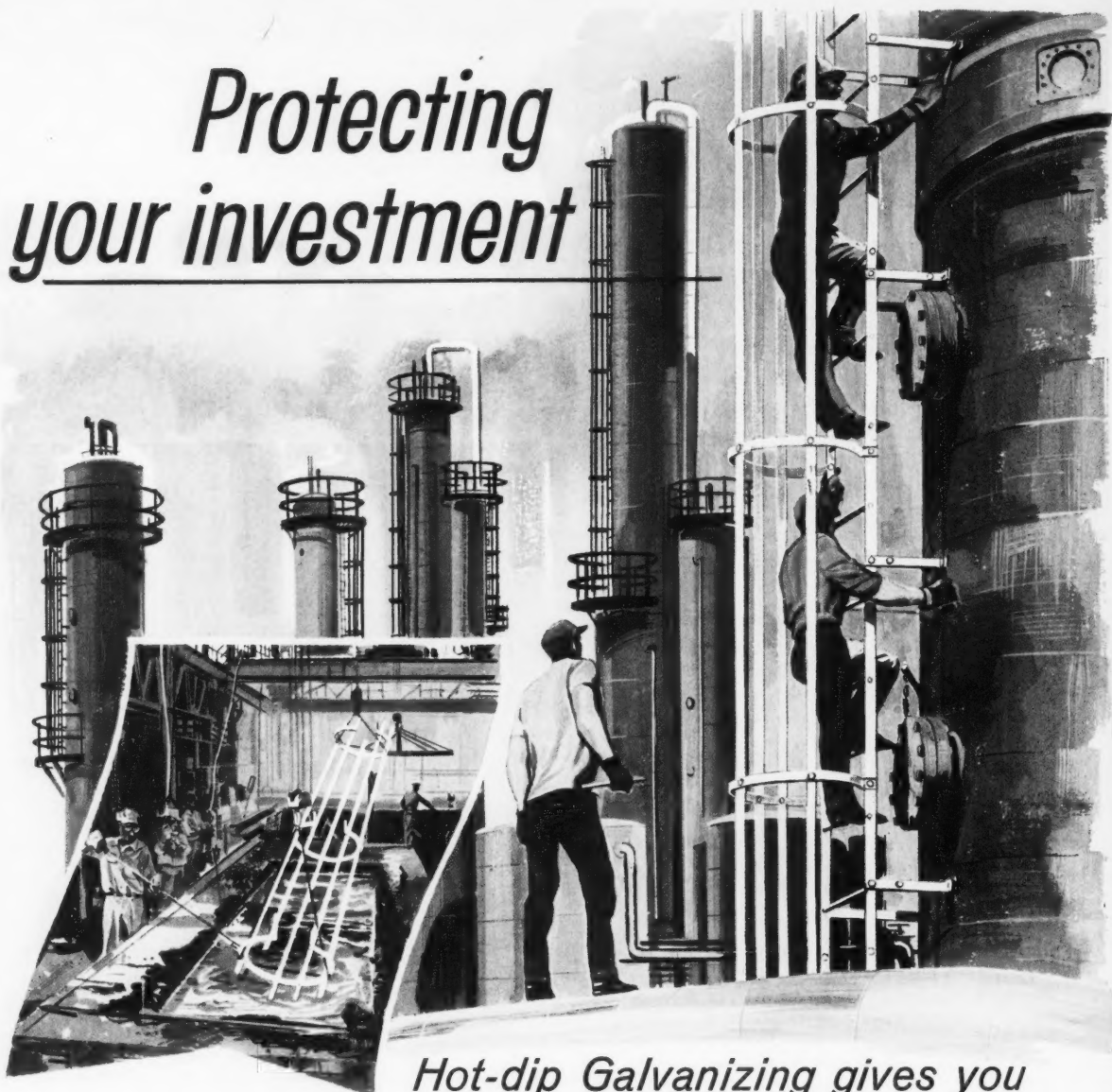
SUBSIDIARY AND AFFILIATED COMPANIES  
CANADA, Edmonton, Alberta • ENGLAND, London  
GERMANY, Frankfurt, a. M. • VENEZUELA, Caracas

#### REPRESENTATIVES

ARGENTINA, Buenos Aires • BRAZIL, Rio de Janeiro • COLOMBIA, Bogota  
ITALY, Rome • JAPAN, Tokyo • KUWAIT, Kuwait • MEXICO, Mexico, D. F.  
NETHERLANDS, The Hague • TRINIDAD, Port of Spain



# *Protecting your investment*



## *Hot-dip Galvanizing gives you dividends in protection*

Nowery J. Smith Co. hot-dip galvanizing gives you *sure* long-term metal protection. Hot-dip galvanizing affords the advantages of complete and uniform zinc coating on complex shapes, inside surfaces and other hard-to-reach areas. Nowery J. Smith Co. has the largest hot-dip galvanizing facilities in the Southwest. Items up to 63-foot structural beams can be

hot-dip zinc galvanized at the Company's Houston plant.

Nowery J. Smith Co. also offers sand and shot blasting, metallizing, prime coating and painting, pickling, oiling, polyvinyl chloride PLASTISOL coating and other special protective coatings. We are exclusive in the Southwest for application of Goodyear Rubber Company's PLIOWELD Linings.

*Call today for complete information on how Nowery J. Smith Co. corrosion protection can give your expensive equipment longer service life!*



## **NOWERY J. SMITH CO.**

Underwood 9-1425

P. O. BOX 7398

8000 HEMPSTEAD HIGHWAY  
HOUSTON 8, TEXAS

ONE OF THE SMITH INDUSTRIES—





# *This Month in Corrosion Control . . .*

**ACCELERATED TESTING** of metals for resistance to erosion and corrosion is described in the Technical Topic beginning on Page 9. Tests were made on several stainless steels, wrought steels, hardened wrought steels, hardened cast steels and a proprietary wrought stainless for use in appliances requiring resistance to erosion and corrosion.

**PUMP AND VALVE PARTS** made of titanium for oil field service have been laboratory and field tested. Described in detail in a Technical Topic beginning on Pages 16 and 17, these tests indicated that titanium is suitable for use in gas lift valves but not suitable for oil well pumps but might perform better if hardened.

**CHLORINATED POLYETHER COATINGS** produced by water suspension system can be used to protect mild steel, stainless, Hastelloys, copper, brass and bronze in a variety of severe conditions, according to the Technical Topic beginning on Pages 32 and 33. Tabular data show some of the inorganic and organic materials which these coatings resist effectively to 200 F. Also given are corrosion tests on these coatings applied in the lab to mild steel.

**RESISTANCE TO DOWN-HOLE CORROSIVES** is claimed for a fibrous polypropylene core for oil field wire. An article on Page 37 describes the wire's satisfactory service for one year as a swabbing line in West Texas with exposures to corrosive acids and temperatures to 280 F.

**EFFECT OF SULFIDE** on corrosion of refinery crude unit overhead equipment is described in an article beginning on Page 86. This study shows that optimum operating conditions are established through careful injection of ammonia to control pH, redox and sulfide content of the overhead water. Application of the findings of this investigation to refinery practice is illustrated.

**ACCEPTABLE CONSTRUCTION MATERIALS** for chemical plant waste disposal facilities are listed with their average corrosion rates in the article beginning on Page 91. This article illustrates the corrosion problems encountered in the biological treatment of chemical wastes and stream pollution abatement. Tests described were conducted in a pilot plant handling liquid wastes from several facilities including a major chemical plant, an oil refinery, a zinc plant, a fertilizer and domestic sewage.

**TWO-THOUSAND HOUR TESTS** were made to determine the suitability of aluminum as a substitute material for nickel for fabrication of military sea water distillation equipment. Reason for this study was to have a substitute material for portable distillation units because nickel would have priority during an emergency for use on missiles, aircraft and other military equipment. See Page 98.

**FOLLOW-UP LEAKAGE CONDUCTANCE SURVEYS** made at 10-mile intervals along 335 miles of pipe with a continuous asphalt mastic coating are discussed on Page 101. This report outlines the methods of test used, describes test results and gives detailed information about coating failures found during this survey.

**CHEMICAL RESISTANCE OF EPOXY RESINS** can be affected by hardener composition, according to the article beginning on Page 104. This experimental procedure involved curing a conventional liquid epoxy resin with five different hardeners. Tests were made in 13 media including hydrochloric acid, nitric acid and caustic soda. Diaminodiphenyl sulfone gave resins the best over-all chemical resistance.

**CAVITATION DAMAGE** and its prevention are discussed from an electrochemical approach in an article beginning on Page 107. A unified theory is given in the relationship between electrochemical and mechanical factors causing damage to materials subject to cavitating environments.





# CONTENTS

This Month in Corrosion Control.....	Page 3
Little Things Are Important for Corrosion Control Success—An Editorial.....	7

## TECHNICAL TOPICS

Accelerated Testing For Resistance to Erosion-Corrosion for Appliance Applications By R. L. Hadley and H. J. Smith.....	Page 9
Laboratory and Field Tests on Titanium for Oil Field Pump and Valve Parts By F. W. Jessen and Ricardo J. Molina.....	16
Discussion: A. H. Roebuck; Reply by F. W. Jessen, Page 30.	
Laboratory and Field Data on Chlorinated Polyether Coatings Produced by Water Suspension System By O. J. Britton, W. A. Carlson and J. R. Little.....	32
Discussions: E. W. Vereeke and Lowell R. Yates; Replies by O. J. Britton, Page 35.	
Technical Topics Scheduled for December.....	19

## RECORD AND REPORT

Page	Page
Swabbing Line's Plastic Core Resists Down-Hole Corrosives.....37	Visco Moves Headquarters to Sugar Land, Texas.....42
Diffraction Reveals Surface Reactions of Metals to Gases.....37	Refractory Materials Sprayed With Electric Arc System.....42
Goodwill Duck Receives Epoxy-Phenolic Paint Job.....37	IBM Seals Thousands of Diodes at One Time With Glass.....44
Book News.....39	Dutch Firm Making Automated Galvanizing Machines.....47
Large Nylon Forms Produced From Caprolactam Monomer.....39	Beryllium Metallurgy Conference Set Dec. 4-5 at N.Y.U.....47
Russia's Corrosion Research Equals Western World's.....39	A.S.T.M. Changes Name.....47
Petroleum Group to Meet in Chicago Nov. 13-15.....39	Lost Wax Casting Used to Make Bone Substitutes.....47
Four Firms Combine Work on Platinized Titanium Electrodes.....40	Engineers Joint Council Moves to New Engineering Center.....47
Reinforced Polyester Tank Designed to Resist Chemicals.....40	Copying Device Scans, Reproduces on Tape.....47
Monsanto to Build Plant in Augusta, Georgia.....42	New Products.....49
	Men in the News.....57

Index to Advertisers.....	6
Advertised in This Issue.....	6
Corrosion Abstracts.....	67

## NACE NEWS

	Page
Forty-three Firms Holding Space at 1962 Corrosion Show.....	59
Products Set for National Show.....	59
South Central Region News 131 From 13 States Attend Oklahoma Course.....	59
Conference Cities Approved for 1962-66.....	59
Central Oklahoma Section.....	61
Teche Section .....	61
Shreveport Section .....	61
East Texas Section .....	61
Deaths .....	61
Canadian Region News Edmonton Section .....	61
Southeast Region News Miami Conference Registration Begins at 9 a.m., Nov. 27.....	61
Ladies' Program Starts with Coffee.....	61
Program Scheduled for Miami Conference.....	61
Ohio Valley Elects Section Officers .....	61
National and Regional Meetings and Short Courses.....	63
North Central Region News T-5D Working on Numbering System for Plastics.....	63
Cleveland Section .....	63
Twin Cities Section.....	63
Kansas City Section.....	63
Southwestern Ohio Section.....	63
Western Region News Portland Section .....	63
San Francisco Bay Area.....	63
Northeast Region News Pittsburgh Section .....	63
Kanawha Valley Section.....	63
Overseas Correspondents CEBELCOR Is Major Corrosion Group in Belgium.....	64
Nine Groups Active in Corrosion Work in Israel During 1960.....	64
Section Calendar .....	64
T-6D Coating Clinic— Questions and Answers.....	65

## DIRECTORY

	Page
NACE Officers, Directors and Staff Members.....	78



# CONTENTS

## TECHNICAL SECTION

	Page
Detection of Interference Current on a Simulated Pipe Line (Topic of the Month) By J. M. Taylor, Jr. and J. P. Barrett.....	79
Sulfide Stress Cracking of Steels for API Grade N-80 Tubular Products By M. F. Baldy.....	81
Oxidation Reduction Potential as a Control Criterion in Inhibition of Refinery Sulfide Corrosion By C. B. Hutchison and W. B. Hughes.....	86
Discussion: A. J. Freedman, Ralph P. Gulley, Page 90; Replies by C. B. Hutchison, Page 90	
Materials of Construction Tested for Chemical Plant Waste Disposal Facilities By Oliver W. Siebert.....	91
Use of Aluminum for Portable Sea Water Distillation Equipment By Richard J. Gainey.....	98
Leakage Conductance Coating Surveys on Asphalt Mastic Coated Pipe By Gerald J. Paisley.....	101
Effect of Hardener Composition on the Chemical Resistance of Epoxy Resins By Frank E. Pschorr.....	104
Discussion: Henry Hasbrouck, Page 105; Ignatius Metil, Page 105; Replies by Frank E. Pschorr, Pages 105 and 106	
The Electrochemical Approach to Cavitation Damage and Its Prevention By H. S. Preiser and B. H. Tytell.....	107
Discussion: J. A. H. Carson, Cdr. E. P. Cochran Jr., Page 115; H. H. Collins, J. T. Crennell, M. G. Duff, Page 116; F. L. LaQue, W. C. Leith, Page 117; J. Z. Lichtman, J. H. Morgan, Page 118; L. M. Mosher, Wm. J. Rheingans, Page 119; T. Howard Rogers, S. Tudor, Page 120; Charles F. Warnock, Page 121; Replies by H. S. Preiser and B. H. Tytell, Pages 115-121	
The Low Potential Zinc Anode in Theory and Application By J. R. Wellington.....	122

### TECHNICAL TOPICS

#### SCHEDULED FOR DECEMBER PUBLICATION

- Crash Repair Program to Control  
Serious Pitting Corrosion on Process Tanks
- Cell Apparatus Checks Resistivity of Nitrogen  
Tetroxide Fuel to Control Corrosion on Missiles
- Corrosion Control Advantages of Polyamide-Epoxy  
Coatings
- Laboratory Tests Show Resistance Properties  
of Urethane Coatings

Published monthly as its official journal,  
by the National Association of Corrosion  
Engineers, Inc., at Houston, Texas, U.S.A.,  
as a permanent record of progress in cor-  
rosion control.

Vol. 17 November, 1961 No. 11

### EDITORIAL STAFF

IVY M. PARKER—Editor

JAMES T. LONGINEAU  
Technical Editor

DALE MILLER  
Editorial Assistant

### EDITORIAL REVIEW COMMITTEE

FRED M. REINHART, Chairman, National  
Bureau of Standards, Washington 25, D. C.

Mark F. Adams	Thomas A. Lowe
A. L. Alexander	D. W. McDowell, Jr.
Joseph Bigos	R. L. McGlasson
W. W. Binger	Dwight G. Moore
W. B. Brooks	Charles C. Nathan
W. H. Bruckner	J. W. Nee
W. E. Bunting	V. B. Pike
I. C. Dietze	J. B. Prime, Jr.
A. C. Elm	W. C. Renshaw
Otto H. Fenner	A. P. Richards
N. D. Greene	A. H. Roebuck
B. C. Haworth	J. D. Sudbury
T. L. Hoffman	D. H. Thompson
Harry J. Keeling	Sidney Tudor
Hugh L. Logan	R. M. Wainwright

### CORRESPONDENTS

Cecil Phillips, Jr.—Petroleum Refining  
K. G. Compton—Telephone, Telegraph and  
Radio  
Leonard C. Rowe—Transportation Industry  
H. E. Stover—Fresh and Salt Water  
W. A. Szymanski—Chemical Industry  
Gordon B. Smith—Non-Ferrous Metals  
W. A. Mueller—Pulp, Paper, Mining and  
Food  
V. M. Kalhaug—Petroleum Production and  
Pipe Lines  
R. J. Schmitt—Ferrous Metals  
Herbert W. Dieck—Power  
Robert E. Brooks—Light Metals

### BUSINESS STAFF

NORMAN E. HAMNER  
Managing Editor and Advertising Manager

T. J. HULL  
(Executive Secretary NACE) Business  
Manager

BRAND and BRAND  
Western States Advertising Representatives  
6314 San Vicente Blvd., Los Angeles 48, Cal.

Address all communications to:  
1061 M & M BUILDING  
Houston 2, Texas

### SUBSCRIPTION RATES (Post Paid)

On sales to Texas addresses, add 2% tax.

#### NON-MEMBERS NACE, CALENDAR YEAR:

U.S. territories & possessions .....\$11  
Canada and Mexico.....\$11  
All other addresses.....\$15

#### SINGLE COPIES, 1959, 60, 61 issues:

Non-members NACE .....\$ 2  
NACE members .....\$ 1  
Single copies 1957, 58 issues.....\$ 2

Libraries of educational institutions and Public  
Libraries, U.S., Canada and Mexico only  
calendar year .....\$ 4

LOST OR DAMAGED COPIES: Claims for re-  
placement without cost must be received within 60  
days of date of issue.

Foreign remittances should be by international  
postal or express money order or bank draft  
negotiable in the U. S. for an equivalent amount  
in U. S. funds. Second-class Postage Paid at  
Houston, Texas.

CORROSION is Indexed Regularly by Engineer-  
ing Index and Applied Science and Technology  
Index.

Copyright 1961 by the National Association of Corrosion Engineers. Reproduction of the contents,  
either as a whole or in part, is forbidden unless specific permission has been obtained from the Pub-  
lishers of CORROSION. Articles presented represent the opinions of their authors, and not neces-  
sarily those of the Editors of CORROSION, nor the officers or Members of the National Association  
of Corrosion Engineers. Manuscripts to be considered for publication should be forwarded, together  
with illustrations, to the Editor of CORROSION, 1061 M & M Building, Houston 2, Texas.





## AMP-O-MATIC WELL CASING

### CATHODIC PROTECTION RECTIFIER

#### Adjusts Output Itself!

Just dial the desired output current, set it and forget it! The AMP-O-MATIC compensates for changes in ground bed or selenium stack resistance, cannot be overloaded and is extremely resistant to lightning damage.

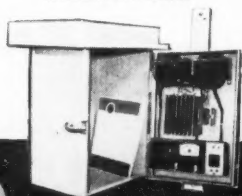
#### FEATURES:

### NEW MAG-AMP

CONTROL has no moving parts, no contacts, no vibration.

- Continuous output adjustment
- Built-in overload protection
- Standard ratings up to 30 amperes
- Economically priced

WRITE FOR DETAILED LITERATURE



GOOD-ALL ELECTRIC MFG. CO. Ogallala, Nebr.  
A SUBSIDIARY OF THOMPSON RAMO WOLDRIDGE, INC.

## ADVERTISED IN THIS ISSUE

	Page		Page		Page
Acid, cleaning	53	Metallic	2	Design, underground	54
Aluminum alloys	43	Pipeline	23, 44, 54, 60	Mastic coating,	
ANODES		Pipeline, internal	23, 38	cold applied	60
Aluminum	45	Plastisols	2	Rock shield	51
Galvanic	43	Plating materials	43	Tapes	45
Graphite	34, 45	Process equipment	23	TAPE	
Impressed current		Tanks	23, 48, 50, 60	Tape, coal tar	58
Inside back cover		Tape	45, 47, 58	Tape, polyethylene	47
Iron, high silicon		Vinyl	21, 52	Wrapping services	44
Inside back cover		Zinc primer	21	PLASTICS	
Magnesium	11, 39, 43, 45	Copper alloys	43	Construction material	31
Plating materials	43	Corrosion engineering	11, 54	Fittings	14, 15
Platinum-titanium	45	Corrosion inspection services	11, 54	Fittings, epoxy	28, 29
Silver	43	Corrosion surveys	54	Pipe	14, 15
Zinc	43, 45, 66	Corrosion testing materials	63	Pipe, glass fiber epoxy	
BACKFILL		Coupons, testing	63	Inside front cover, 28, 29	
Clay	45	PIPE FITTINGS		Pipe, lined	14, 15, 38
Coke	45	Epoxy	28, 29	Polyethylene coated pipe	44
Coke breeze	61	Plastic	14, 15	Process equipment	14, 15
Bushings, nylon reinforced	65	Flaw detector	42	Resin, glass reinforced	46
CATHODIC PROTECTION		Floor coatings	49	Tape	45, 47
Anodes	11, 34, 39, 43, 45, 66	Galvanizing materials	43	Tubes, linings	56
Inside back cover		Generators, thermoelectric	45	Plating materials	43
Backfill, coke or clay	61	INHIBITORS		PROCESS EQUIPMENT	
Bushings, nylon reinforced	65	Acid	53	Design services	25, 46
Design	39, 45, 54	Oil well	36	Monel	25
Engineering services	11, 39, 45, 54	Oil and gas wells	Back cover	Nickel alloy lines	25
Equipment and materials	11, 39, Inside back cover	Petroleum	1, 36, 39, Back cover	Plastic hoods, ducts,	
Hot tapping tool	45	Refinery	39	tanks	31
Installation services	11, 39, 45, 54	Tanks	41	Tanks, reinforced polyester	
Materials	11, 39, 45, 54	Inspection	54	resin	46
Inside back cover		INSTRUMENTS		Rectifiers	6, 39, 45
Rectifiers	6, 39, 45	Flaw detector	42	Rock shield	51
Surveys	39, 45, 54	Transducer	42	Rust prevention	54
Thermoelectric generators	45	Lead sheet, pipe,		Sand and shot blasting	2
COATINGS		fittings	43	Salt, synthetic sea	64
Analysis services	52, 54	LININGS		Spray guns	18
Application equipment	18	Tanks	48, 50	TANKS	
Application services	2, 38, 44, 54	Tubular goods	56	Coatings	23
Chemical resistant	24, 52	Nickel alloys	25	Glass reinforced polyester	
Coal tar tape	58	PIPE		resin	46
Custom service	2	Epoxy resin, reinforced		Linings, plastic	48
Enamels	52	Inside front cover, 28, 29		Mastic coatings	60
Epoxy	21, 52	Fittings, epoxy	28, 29	TANK LININGS	
Floor	49	Plastic	14, 15	Glass	50
Heat resistant	52, 55	Plastic lined	14, 15, 38, 56	Plastic	48
Hot dip zinc galvanizing	2	Steel, plastic coated	14, 15	TAPES	
Industrial	55	PIPELINE		Coal tar	58
Inorganic zinc	8	Coatings	54	Plastic	45
Mastics, cold applied	60	Coating, application service	23, 38	Polyethylene	47
		Coating, plastic	23, 38	Testing services	54
		Coating, polyethylene	44	Test supplies	63
		Coating services	44	Tubular linings, plastic	56
		Construction	54	Transducer	42
				Wrapping	54
				Zinc and zinc alloys	43

## INDEX TO ADVERTISERS

Vol. 17

November, 1961

No. 11

Amchem Products, Inc.	43	Humble Oil & Refining Company	36
Amercoat	Inside Front Cover	Huntington Alloy Products Division	
American Cyanamid Company		The International Nickel Company, Inc.	25
Plastics and Resins Division	46	Lake Products Company	64
Arno Adhesive Tapes, Inc.	47	Markal Company	55
Atlas Chemical Industries, Inc.		Midwestern Pipe Line Products Company	51
Chemicals Division	31	National Association of Corrosion Engineers	62
Branson Instruments, Inc.		National Carbon Company	
Ultrasonic Test Div.	42	Division of Union Carbide Corporation	34
Carboline Company	8	Plastic Applicators, Inc.	38
Cathodic Protection Service	45	Positions Wanted and Available	40
Celcote Company, The	50	Resistoflex Corporation	14, 15
Central Plastics Distributing Co.	65	Royston Laboratories, Inc.	60
Consolidated Mining and Smelting Company of Canada Limited, The	66	Smith, Nowery J. Company	2
Corrosion Engineering Directory	54	Standard Pipeprotection, Inc.	44
Corrosion Rectifying Company	39	Steelcote Manufacturing Company	49
Corrosion Services, Inc.	11	Tapecoat Company, The	58
Corrosion Test Supplies	63	Tretolite Company, Division	
DeSoto Chemical Coatings, Inc.	42	Petrolite Corporation	1
DeVilbiss Company, The	18	Tube-Kote, Inc.	23
Dowell	Back Cover	Tubular Lining Corporation	56
Duriron Company, The	Inside Back Cover	U. S. Stoneware Company	21
Federated Metals Division		Universal Oil Products Company	
American Smelting & Refining Company	43	Products Department	41
Fibercast Company		Valdura Division	
Div. Youngstown Sheet & Tube Co.	28, 29	American-Marietta Company	24
Garlock, Inc.	48	Wholesale Coke Company	61
Good-All Electric Manufacturing Co.	6	Youngstown Sheet & Tube Company	
		Fibercast Division	28, 29



# Little Things Are Important for Corrosion Control Success

**I**MPATIENCE with and inattention to small details by one who otherwise follows the best practices in seeking to prevent corrosion may produce failure when success is fully certain otherwise. The ability to handle details, more often than not, marks the man who can be relied on to do a satisfactory job. One who cannot handle them may be successful, or may not; at best his performance will be unpredictable.

Examples of the care and foresight required to carry out successfully a corrosion control scheme are given below. These are only a few of the many similar examples that could be cited. They also show why the corrosion worker must know what he is doing. They show, in some cases, that very close supervision over the work of others may be required to make success certain.

## Case No. 1—The Overlooked Blasting Debris.

A phenolic coating inside a brewery tank perforated when workmen hand-cleaning the tank stepped on the bottom, grinding sand from the surface preparation step (and overlooked in vacuuming the tank) into the coating spread over it, causing pinholes. It was necessary to add cathodic protection to avoid product contamination by rust.

## Case No. 2—Add Enough Fluoride to Passivate.

Hafnium-free zirconium's corrosion rate in hydrofluoric acid will be increased when small amounts of fluoride are added. When larger amounts are added, however, passivation ensues. Moral: Be sure to add enough.

## Case No. 3—Be Sure You Are Really Remote.

Potential readings taken in the vicinity of a cathodically protected underground structure can be misleading. Finding the so-called "remote ground" to obtain reliable data involves both an understanding of electrical circuitry and of the effect of protected and unprotected structures in the environment as well as the unavoidable errors in the accuracy of measurements. The novice, following what he believes to be well-founded principles in taking his measurements, may nevertheless be led to completely false conclusions if he selects reference points which happen to be in the wrong part of the electrical field or fails to take errors in measurements into account.

## Case No. 4—Unexpected Contents of Commonly Used Materials.

Corrosion of mating surfaces attributed to various causes, including galvanic corrosion, may in fact be a result of chlorides in packing. The care that must be used in selecting what otherwise is a relatively unimportant material is understood when it is realized that chlorides in asbestos yarn may be as much as 115 ppm. Also there is a difference between the corrosion reactions of natural and artificial graphite in some aqueous environments.

## Case No. 5—The Better Material Sometimes Isn't.

In packaging zinc plated materials for storage, especially in humid environments it would seem logical to choose a plywood box over a corrugated carton. Experience shows, however, that in many instances there will be less corrosion of the plated materials in the cardboard carton than in the wooden box. This happens because acetates sometimes present in plywoods may be leached out by vapor and accelerate corrosion.

## Case No. 6—Welding Slag Needs to Come Off.

Don't go halfway in removing welding slag before painting. Pre-oiling of the surface to be welded will reduce cleaning time by two-thirds to three-quarters. If you leave the slag on, your coating will fail. Sandblasting is the preferred method of removal, if you want to be sure.

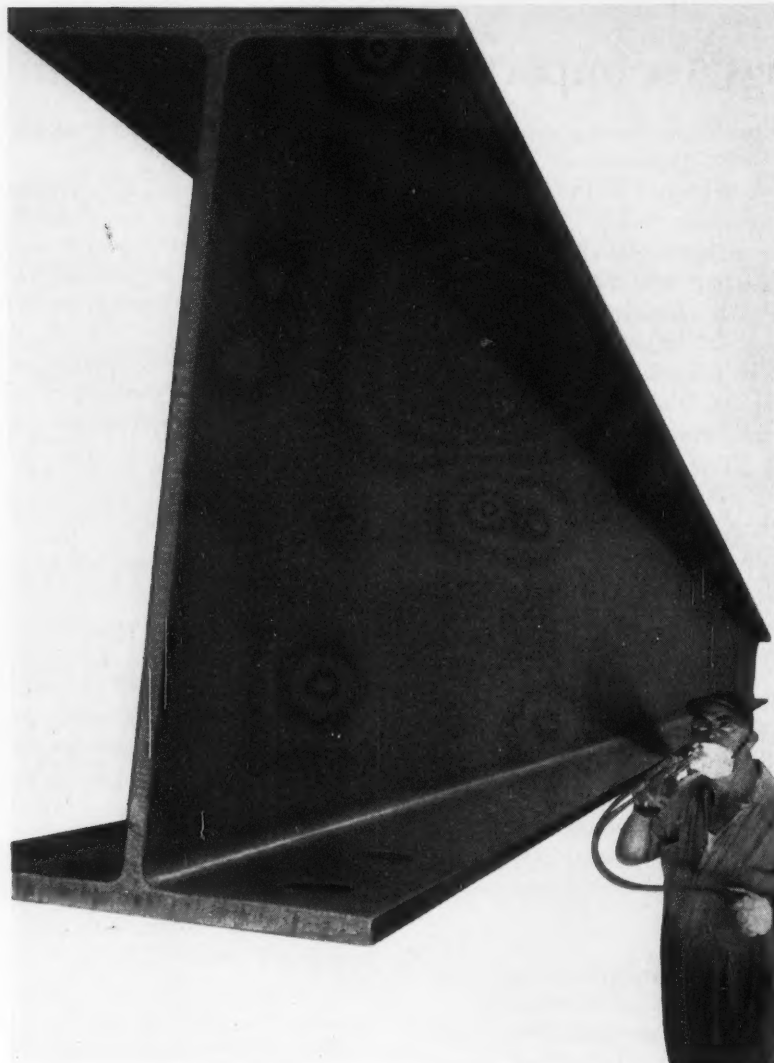
## Case No. 7—Use Any Old Bolts When You Bury Them.

This is a false doctrine. Select bolts for fastening structures to be buried or submerged with care. They should be selected to be cathodic to the metals with which they are connected. Bolts which are anodic may fail rapidly, especially if the environment is very aggressive.

## Case No. 8—Beware of Crevice Corrosion With Titanium.

In some acidic environments in which it is normally passive, titanium will corrode when crevices of certain geometry exist. When fabricating titanium, therefore, extreme care must be used to avoid these crevices. A little extra care here makes the difference between success and failure.





## All the advantages of hot-dip galvanizing PLUS job-site application with CARBO ZINC 11



INORGANIC ZINC COATING is rapidly gaining recognition as the ultimate for basic protection of steel. For example, a large Gulf area chemical plant now under construction specified zinc—both hot-dip galvanizing and Carbo Zinc 11 inorganic zinc coating. Both methods are equal in performance and galvanic protection—the choice is a matter of economics.

HOT-DIP GALVANIZING is generally best for small pieces and irregular shapes: handrails, angles, floor gratings, ladders, etc.

CARBO ZINC 11 is best where these exclusive advantages count:

- Application can be made on the job-site.
- Old steel, in place, can be galvanically protected.
- Repairs can be made in the field.
- Field welding can be touched up.
- Only one side need be coated, such as storage tanks.
- All sizes and shapes can be coated.

EASY TO APPLY with spray or brush in any kind of weather. Water insoluble in 20 minutes. WRITE for analysis of costs "When to Hot-Dip Galvanize—and When to Use Carbo Zinc 11."

*Maintenance Coatings with Experience...*



32-A Hanley Industrial Ct. • St. Louis 17, Mo.





# TECHNICAL TOPICS

## For Appliance Applications

**R. L. Hadley and H. J. Smith**  
General Electric Company  
Louisville, Kentucky

## for Resistance to

## Erosion-Corrosion\*

### Abstract

Because some metals used in appliances must have both erosion and corrosion resistance, a series of accelerated tests was made on several stainless unhardened wrought steels, hardened wrought steels, hardened cast steels and a proprietary wrought stainless iron. Tests consisted of exposing specimens for 100 hours in a continuously circulating 4 percent NaCl solution at 150 F with aluminum oxide pellets as abrasive. Rotating test vessel was inclined to produce tumbling action of pellets. Both weight and edge losses were considered in judging results. Cast 420 or wrought 431 stainless steel was found to perform best. 2.3.2, 3.5.3

### Introduction

**N**UMEROUS APPLICATIONS of materials in appliances require good resistance to both corrosive action and abrasion. Unfortunately, metals economically applicable in appliances and which have the required resistance to corrosion, aluminum, stainless steel and copper, for example, are not notably high in abrasion resistance.

Both properties can be improved by means of porcelain enamel, sprayed metal coatings, anodizing, or by alloying, to produce such materials as hardenable stainless steels or beryllium copper. Coatings, however, have limited usefulness because of brittleness, processing problems, and lack of continuity.

Abrasion and/or corrosion affect appliances in one or more of the following ways:

1. Perforation of enclosure walls.
2. Loss in structural strength.
3. Increased clearances between mating parts.
4. Changes in contour of cutting edges.

Geometry of sample and measurement techniques which would coordinate with

material performance in service was an important aspect of the investigation reported here.

### Earlier Investigations Scanned

Earlier investigations in this general area have dealt with the following effects in corrosive environments:

1. Cavitation
2. Erosion (liquid)
3. Abrasion resistance (solids)
4. Impact, mechanical properties

Work by Copson<sup>1</sup> on cavitation, Champion<sup>2</sup> and Wormwell<sup>3</sup> on cavitation and liquid erosion, and Fontana<sup>4</sup> on erosion-corrosion reported some mechanisms and material observations pertinent to the interrelated effects of corrosion and wear. A generally applicable method of comparing material performance was not presented, however.

While hardenable stainless steels appear to fit the requirements outlined, they differ widely in their performance. Some non-hardenable stainless steels were included in this study because of their utility in supporting other cutting materials and to increase the spread of corrosion resistance data so comparative measurements could be made more accurately of the importance of that property.

Evaluation of hardenable stainless steels involves the effect of carbon con-

tent necessary for high hardness levels on this corrosion resistance.

Bloom<sup>5</sup> investigated the effects of heat treatment of quench-hardenable stainless steels on their corrosion resistance and mechanical properties. His findings confirmed earlier work by Bain, Aborn, and Rutherford<sup>6</sup> and Mears and Brown<sup>7</sup> on the effect of chromium depletion due to carbide formation and the subsequent lowering of corrosion resistance.

### Experimental Procedures

To carry out the studies reported here, a laboratory testing device was developed which consisted of rotating ceramic container inclined at 45 degrees in which rectangular 1 by 1/4 by 1/8 specimens were supported (Figure 1). Approximately one half of the specimen area was masked, using an epoxy resin, and the specimen was so mounted that only half the surface area was exposed to the test environment (Figure 2).

The environment consisted of a continuously circulating 4 percent NaCl solution heated in a constant 150 F temperature bath and pumped into the test vessel and out for reheating.

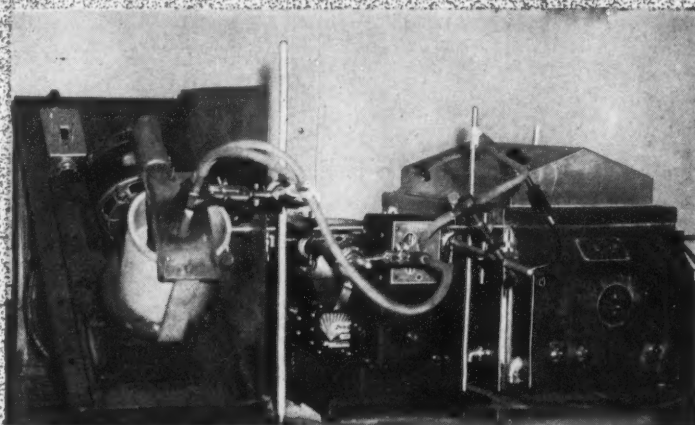
Each specimen was degreased, dried, passivated in 1-1 HNO<sub>3</sub> for 5 minutes at 150 F and carefully weighed before mounting. A measured number of aluminum oxide pellets (3/8 inch dia.) was

(Continued on Page 10)

\*A paper presented under the title "Erosion-Corrosion Testing of Metals," at the 17th Annual Conference, National Association of Corrosion Engineers, Dallas, Texas, March 14-18, 1960.

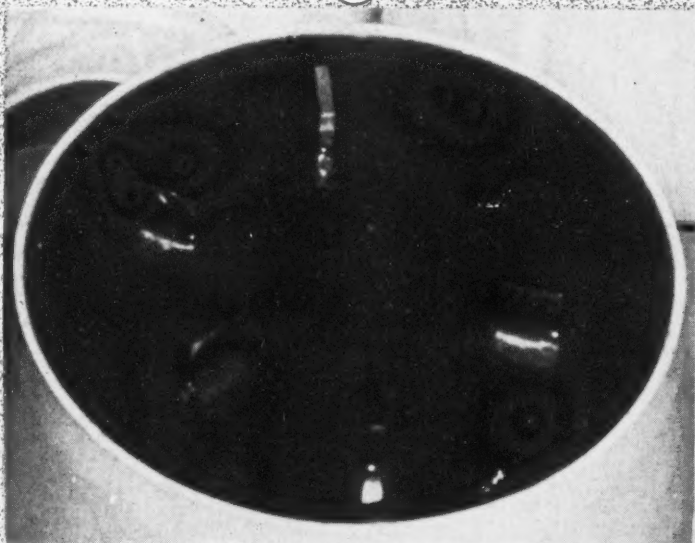


## Erosion—



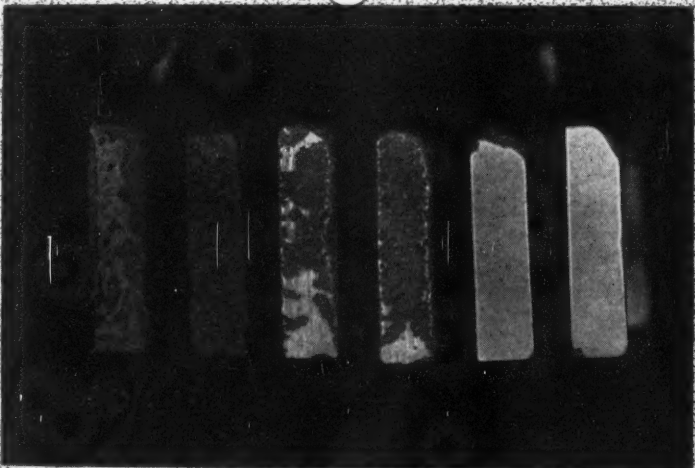
1

Figure 1—Wear-corrosion test mechanism.



2

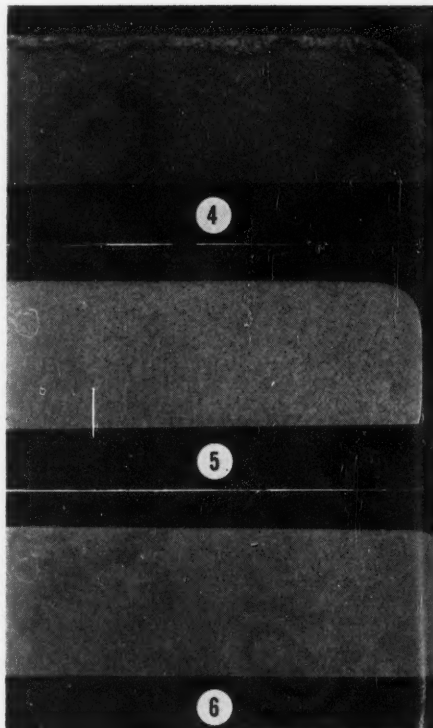
Figure 2—Method of mounting specimens for wear-corrosion tests.



3

Figure 3—Wear-corrosion specimen after testing, before cleaning.

Figures 4, 5 and 6—Edge of three specimens after 100 hours in 4 percent NaCl solution at 150 F with aluminum oxide abrasive. Etchant: Marbles' reagent. 10X. Figure 4 is AB-1 cast stainless alloy (Hardness Rc 62), Figure 5 is cast 421 stainless steel (Hardness Rc 48), and Figure 6 is cast 420 stainless steel (Hardness Rc 50).



4

5

6



## -Corrosion

(Continued From Page 9)

added in the test vessel whose angle of inclination produced tumbling action for the abrasive test. The specimen holder was clamped so the specimens were in a fixed position relative to the ceramic test vessel which rotated at 75 rpm. Continuous Rotation and Circulation.

Tests were conducted for 100 hour cycles with continuous rotation and circulation of solution. At the end of each cycle specimens were washed and the protective epoxy masking material removed from the lower half of the specimen by thermal shock consisting of immersion in liquid nitrogen followed by immersion in boiling water. Specimens then were cleaned in 1-1 HNO<sub>3</sub>, dried and weighed. Typical specimens are shown in Figure 3. A second acid cleaning and weighing was made to establish a blank or cleaning weight loss value but correction was found necessary in few instances. In addition to the weighing of each specimen before testing, radius measurements were made on the four completely exposed edges of the specimen using a projection comparator and these values were recorded. At the conclusion of the test, radius measurements were made again and edge deterioration thus was noted in a quantitative manner.

Edge volume loss was calculated so variations in contour changes of different edges of a given specimen due to differences in orientation could be averaged. It was felt this measurement could be applied to appliance components as well to establish service performance and variations in environment.

### Pits Are Carefully Studied

In addition to weight loss values and edge radii measurements careful observation was made of pit numbers and maximum pit depth measurements were made on each specimen where necessary. Initial experiments were made without masking the lower half of the test specimen in order to include crevice attack effects. Because clamping pressures and crevice areas varied it was not deemed feasible to include this factor in the current test program.

Tests were carried out on the following stainless steels: Wrought 430, 410, 410 (HT), 431, 302 and 17-7 PH; Cast 420, 431 and proprietary high carbon stainless iron (AB-1). Nominal composition is in Table 1.

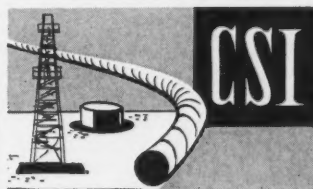
All tests were run in duplicate and comparative test runs were made in 4 percent NaCl solution and water to separately assess the effects of abrasion and corrosion.

(Continued on Page 12)

TABLE 1—Nominal Composition of Stainless Steel Test Specimens

	C	Cr	Ni	Si	Mn	Mo	Cu	V
Cast 420SS.....	0.33	13.85	0.23	0.65	0.59	0.16	tr	....
431SS.....	0.30	16.75	1.76	0.68	0.51	0.14	tr	....
High Carbon Stainless Steel.....	3.30	18.00	0.4	0.25	0.8	1.00	..	4.00
Wrought 302.....	0.10	18.0	8.0					
430.....	0.10	16.0	....					
410.....	0.14	12.5	....					
431.....	0.17	16.0	2.0					
17-7 PH.....	0.07	17.0	7.0					

(Aluminum 1.25)



Practical ideas  
to help you  
Stop CORROSION

### HOW YOU SAVE MONEY BY USING "HIGH POTENTIAL" RATHER THAN "STANDARD" MAGNESIUM ANODES

Why do you use magnesium anodes to stop corrosion of pipe lines, tank bottoms, oil well casing, etc.—rather than other types of galvanic anodes that sell for less money per pound?

The answer is, of course, because magnesium gives you a lower overall cost for cathodic protection. Magnesium's higher potential (approximately 0.4 volts) makes it possible to achieve protection with fewer installations.

If the above is true, then it follows that a "high potential" magnesium anode (delivering approximately 0.3 volts more than regular magnesium) can give you an even lower overall cost. This would be especially true if there is no sacrifice in useful ampere hours of current per pound.

Galvomag, the high-potential magnesium anode developed by The Dow Chemical Company, meets both of these requirements: It delivers 20 to 35 per cent more current than standard H-1 alloy magnesium anodes; and it has a current efficiency (ampere hour rating) comparable to H-1 anodes. Other so-called "high potential" and "high current" anodes tested, however, do not show current efficiencies in a comparable range.

To help you get the most for your magnesium anode dollar, we suggest that you specify Galvomag or its equivalent in solution potential and ampere hour rating.

CSI engineers—pioneers in cathodic protection—have also developed a wide variety of special sizes and shapes to make Galvomag even more efficient. For example, the use of these special sizes in "hot spot" protection of pipe lines makes it possible to lower the number of anodes required by one-third—without decreasing the amount of protection or shortening the life of the installation.

It will pay you to check with CSI—for expert engineering and installation services, plus a complete line of cathodic protection supplies for both rectifier and anode installations. Prices are competitive. Call or write today.



Cleveland 13, Ohio  
1309 Washington Ave.  
Tel. CHerry 1-7795

### CORROSION SERVICES INCORPORATED

General Office: Tulsa, Okla.

Mailing Address:

Box 787, Sand Springs, Okla.  
Tel. Circle 5-1351



## Erosion— —Corrosion

(Continued From Page 11)

### Discussion of Results

Weight loss measurements of specimens were calculated on the basis of weight lost per unit area of sample exposed.

Radius change measurements were used in volumetric determinations of metal removed from the edges subject to deterioration. These data are presented in Table 2. A summary of ratings for the materials tested is shown in Table 3. Best rating: Cast 420, wrought (low carbon) 431.

Materials tested fall into three categories: (1) unhardened wrought steels, (2) hardened wrought steels, (3) hardened cast steels. In order for any ranking of materials to be significant it is

**TABLE 2—Wear-Corrosion Test Summary  
(4 Percent NaCl)**

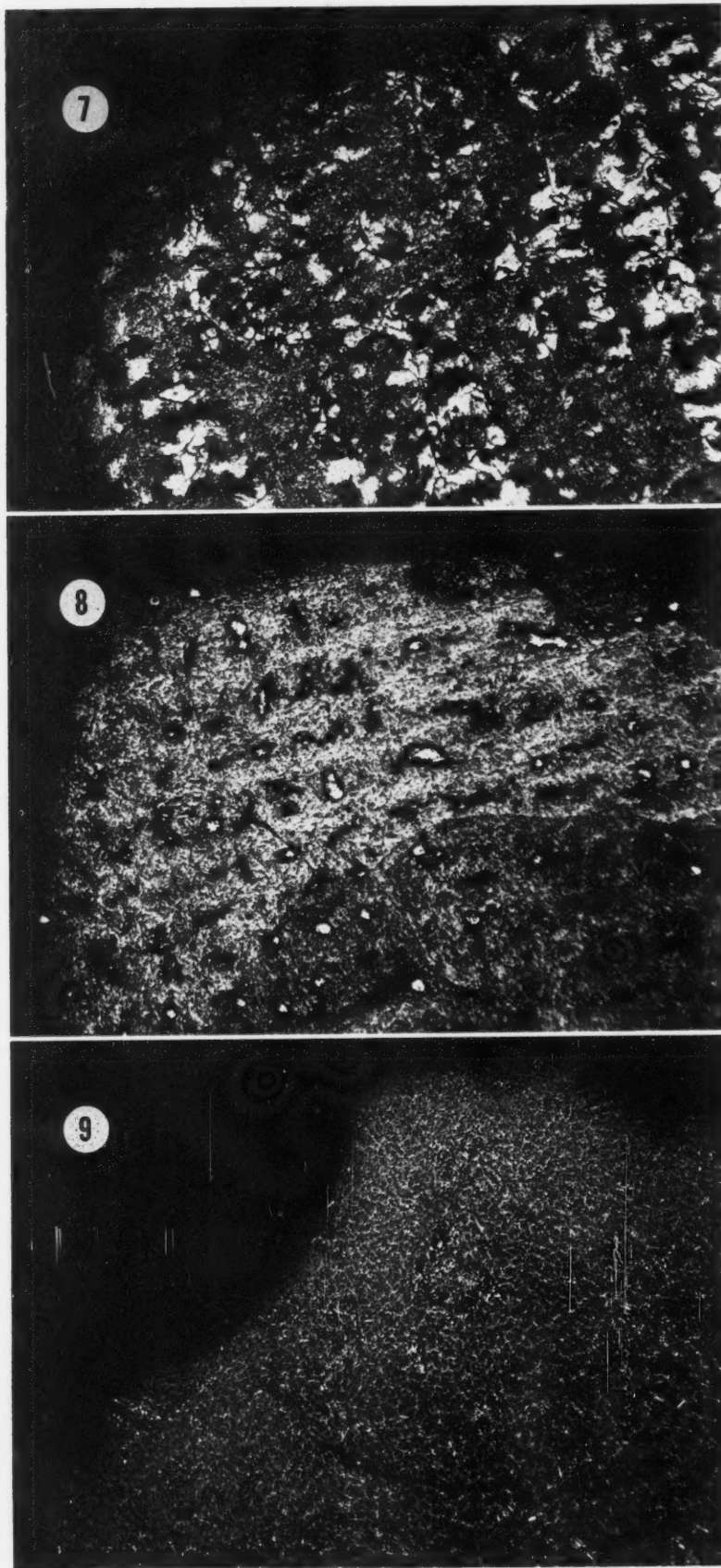
Material	Hard- ness	Edge- Volume Loss <sup>(1)</sup>	Weight Loss <sup>(2)</sup>
<b>WROUGHT</b>			
302.....	Rb 85	56.6	.0118
302.....	Rb 85	43.2	.0130
430.....	Rb 84	49.9	.0170
430.....	Rb 84	43.1	.0178
410.....	Rb 80	53.9	.0363
410.....	Rb 80	61.6	.0403
17-7 PH....	Rc 47	33.5	.0147
17-7 PH....	Rc 47	24.3	.0192
431.....	Rc 39	17.7	.0135
431.....	Rc 39	17.6	.0118
410 (HT)...	Rc 44	29.5	.0180
410 (HT)...	Rc 44	25.7	.0135
<b>CAST</b>			
AB-1.....	Rc 61	37.2	.0387
AB-1.....	Rc 61	41.4	.0379
431.....	Rc 48	31.4	.0120
431.....	Rc 48	36.5	.0157
420.....	Rc 50	11.8	.0170
420.....	Rc 50	13.6	.0154

<sup>(1)</sup>  $\times 10^{-6}$  in.<sup>3</sup><sup>(2)</sup> Grams.

**TABLE 3—Wear-Corrosion Test Ranking**

Material	LOSS BASIS		
	Hard- ness	Edge- Volume	Weight
<b>WROUGHT</b>			
302.....	Rb 85	8	1
430.....	Rb 84	7	7
410.....	Rb 80	9	8
17-7 PH....	Rc 47	4	6
431.....	Rc 39	2	3
410 (HT)...	Rc 44	3	4
<b>CAST</b>			
AB-1.....	Rc 61	6	9
431.....	Rc 48	5	2
420.....	Rc 50	1	5

Figures 7, 8 and 9—Microstructures of three materials, hardened and drawn. 100X. Etchant: Marbles' reagent. Figure 7 is cast 431 stainless, Figure 8 is cast 420 stainless and Figure 9 is AB-1 cast stainless alloy.





necessary to weight the materials against desired characteristics which are:

1. Retention of a sharp edge.
2. Resistance to pitting.
3. Resistance to general abrasion, corrosion.

#### Careful Examination Necessary

Not only was the gross amount of weight lost important but also whether it was removed from an edge or a flat surface and whether or not edge attrition as smooth and regular or roughened by pitting. Thus careful examination of specimens is as necessary as physical measurements in properly evaluating materials.

A specific application of the test method was made in evaluating three cast stainless materials for a grinding component. Type S431 and 420 and a proprietary cast high carbon stainless iron were tested for 100 hours in 4 percent NaCl solution at 150 F. Comparable edges of test specimens after testing are shown in Figures 4, 5 and 6. Microstructures of these three materials are shown in Figures 7, 8 and 9.

Microexamination of the wear edges of the specimens at a higher magnification (Figures 10, 11 and 12) clearly show intergranular attack on the material. This may be ascribed to a chromium depletion adjacent to the grain boundaries caused by the formation of chromium carbides due to the high (3 percent) carbon content in the proprietary composition. While the attack on the 431 is less than on the other two materials its resistance to abrasion is poor due to its lower hardness and retained austenite. The 420 material shows the best balance in resistance to abrasion and corrosion. This evidence, coupled with other test data, showed the high carbon stainless to be the poorest material for the intended application even though it had the highest hardness value of any of the materials tested.

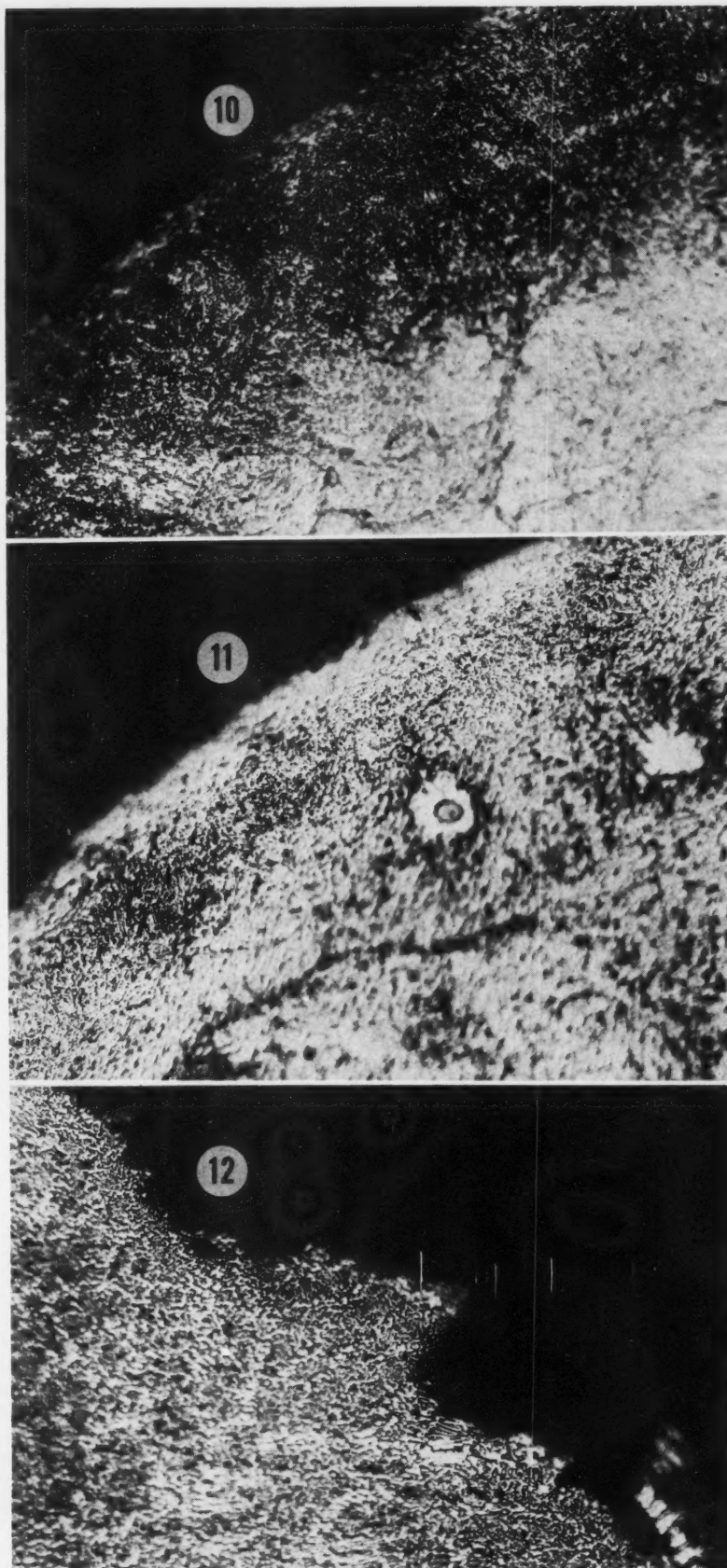
#### Conclusions

1. Edge-volume loss measurements made under accelerated corrosive wear conditions showed good correlation with qualitative service performance of materials used for cutting edges in mild corrosive environments.
2. Weight loss measurements did not reflect cutting edge attack with adequate sensitivity.
3. Observation or crevice attack and localized pitting is a required supplemental measurement.
4. In a specific material application, the test pointed to the superiority of cast 420 stainless steel or wrought 431 stainless steel for cutting edges.

#### References

1. Copson, *Ind Eng Chem*, **44**, 1745, (1952).
2. Champion, *Corrosion Testing Procedures*, Wiley, 1952.
3. Wormwell, *J Iron Steel Inst*, **154**, 219 (1946).
4. Fontana, *Ind Eng Chem*, **44**, 101, (1952).
5. Bloom, *Corrosion*, **9**, 56-65 (1953).
6. Bain, Aborn and Rutherford, *Trans Am Soc Steel Treating*, **21**, 481, (1933).
7. Mears and Brown, *Ind Eng Chem*, Aug. 1941, P. 100.

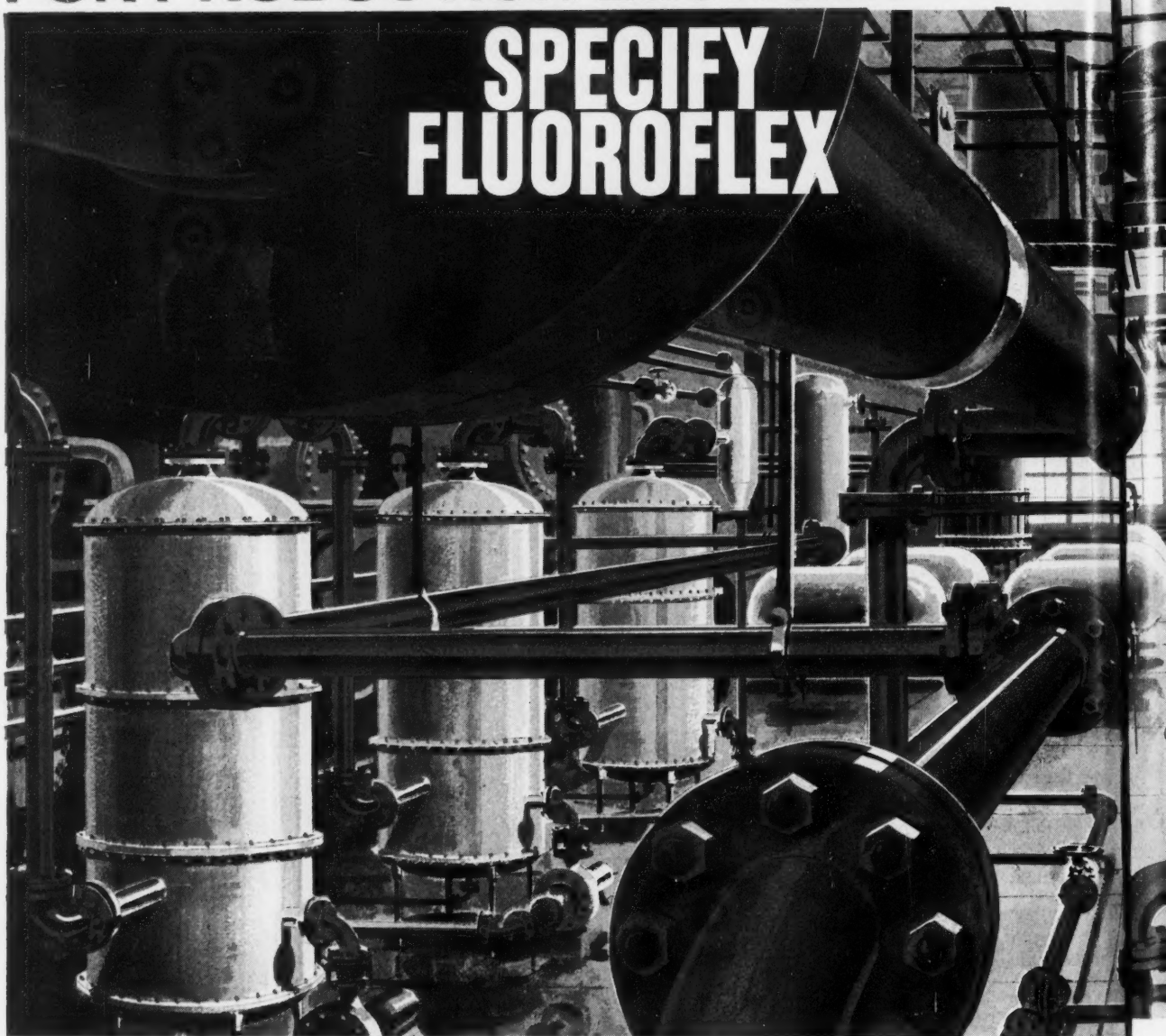
Figure 10—Good corrosion resistance, negligible grain boundary attack. Retained austenite contributes to lower hardness. Type 431 stainless (Rc 48). Etchant: Marbles' reagent. 500X. Figure 11—Good corrosion resistance, negligible grain boundary attack. Structure primarily martensite. Type 420 stainless (Rc 50). Etchant: Marbles' reagent. 500X. Figure 12—Poor corrosion resistance, heavy grain boundary attack. Structure martensitic with iron and chromium carbides. AB-1 cast stainless alloy (Rc 62). Etchant: Marbles' reagent. 500X.





## FOR PRODUCTION ECONOMY

# SPECIFY FLUOROFLEX



## TO STOP CORROSION, DOWNTIME, AND

The complete inertness of Fluoroflex\*, Resistoflex's specially processed Teflon† construction material, is well known. The fact that Fluoroflex exhibits zero corrosion to all acids, chemicals, and solvents up to 500°F. (except free fluorine and alkali metals at elevated temperatures) is one reason for the completely successful and satisfactory use of Fluoroflex in hundreds of process plants both here and abroad.

Because of this superior performance, one might expect a Fluoroflex system to be more expensive than it is. However, on an installed cost basis, Fluoroflex-lined steel piping is today comparable with or cheaper than pressure-piping of several high-nickel alloys.

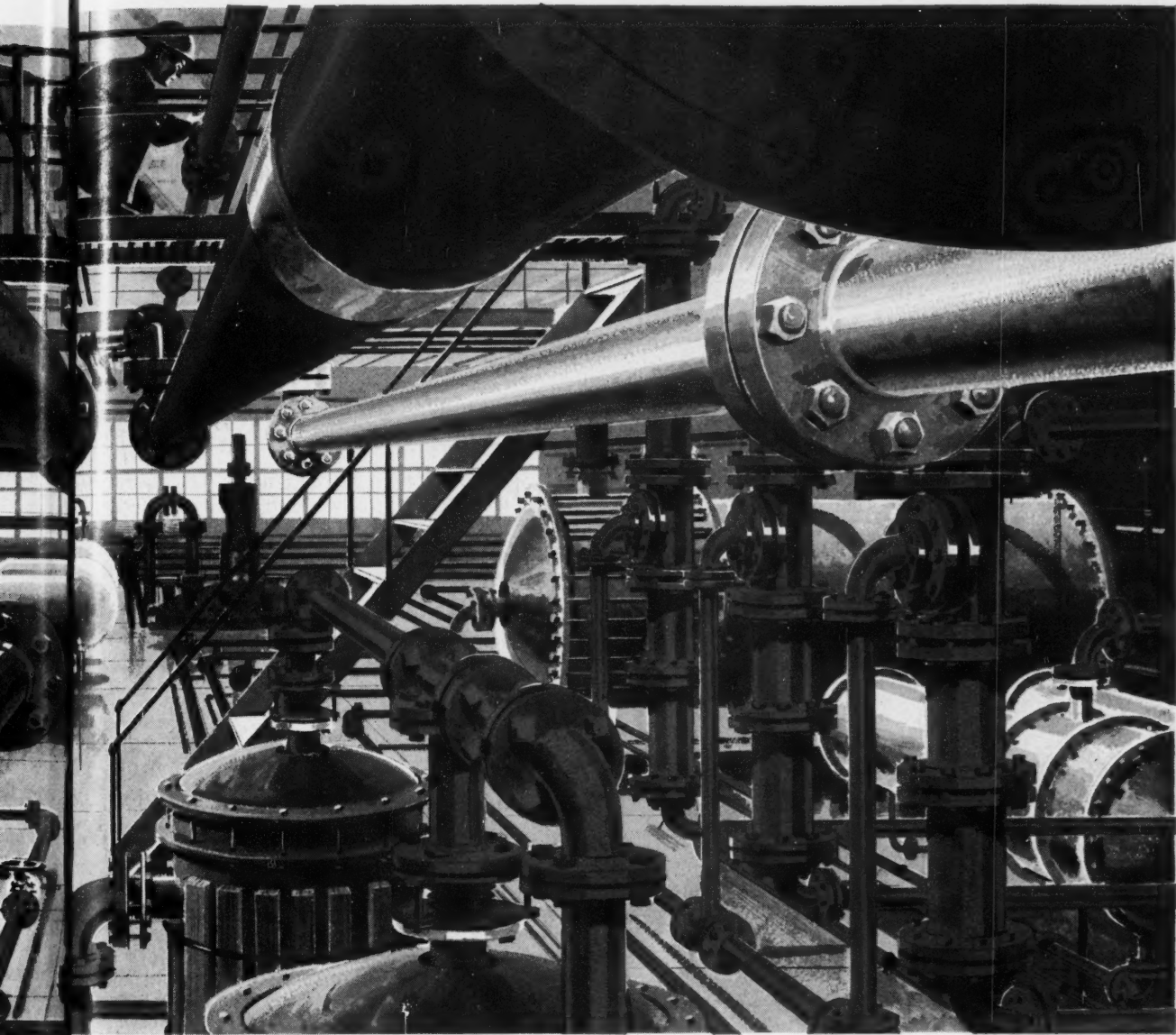
As a result leading engineering-construction firms now use Fluoroflex rigid piping systems and flexible components in new plant construction to stop corrosion or contamination and to reduce erection costs.

Many small processing columns can be assembled from sections of Fluoroflex-lined pipe for rectifying, absorption, and scrubbing operations. Packed Fluoroflex-lined columns complete with Fluoroflex distributor and support plates and Raschig rings can be fabricated in sizes up to 10 inch diameter.

■ Fluoroflex preflanged piping eliminates cutting, chamfering, cleaning, welding, scale, flux, weld spatter and

SEE US AT THE CHEMICAL INDUSTRIES SHOW, BOOTHS 893, 895, 897.





## PRODUCT LOSSES

annealing—minimizes the need for gaskets, hangers, supports, and anchors as required for non-metallic piping.

■ **Fluoroflex reinforced bellows** absorb vibration loads on centrifuges and pumps, and reduce packing leakage. They correct misalignment and expansion-contraction problems on rigid vessels, towers, heat exchangers, etc.

■ **Fluoroflex transfer hose** combines contamination-free hose and flanges with rugged flexibility. Prevents clogging of strainers at critical moments of charging and unloading vessels, tank cars, etc.

■ **Fluoroflex dip pipes, spargers, and thermowells** provide the protection of Teflon with the strength of steel to withstand severe agitation or viscous materials without danger

of damaging expensive reaction vessels.

*If you have corrosive fluid-handling problems, SPECIFY FLUOROFLEX. Write to Resistoflex Corporation for detailed information today, or ask our local service engineer to call. Plants in ROSELAND, N. J., Anaheim, Calif., Dallas, Tex. Sales offices in major cities.*

\*Resistoflex T.M.

†DuPont T.M.

# RESISTOFLEX RELIABILITY

COMPLETE SYSTEMS FOR CORROSIVE SERVICE

N. Y. COLISEUM • NOV. 27 TO DEC. 1



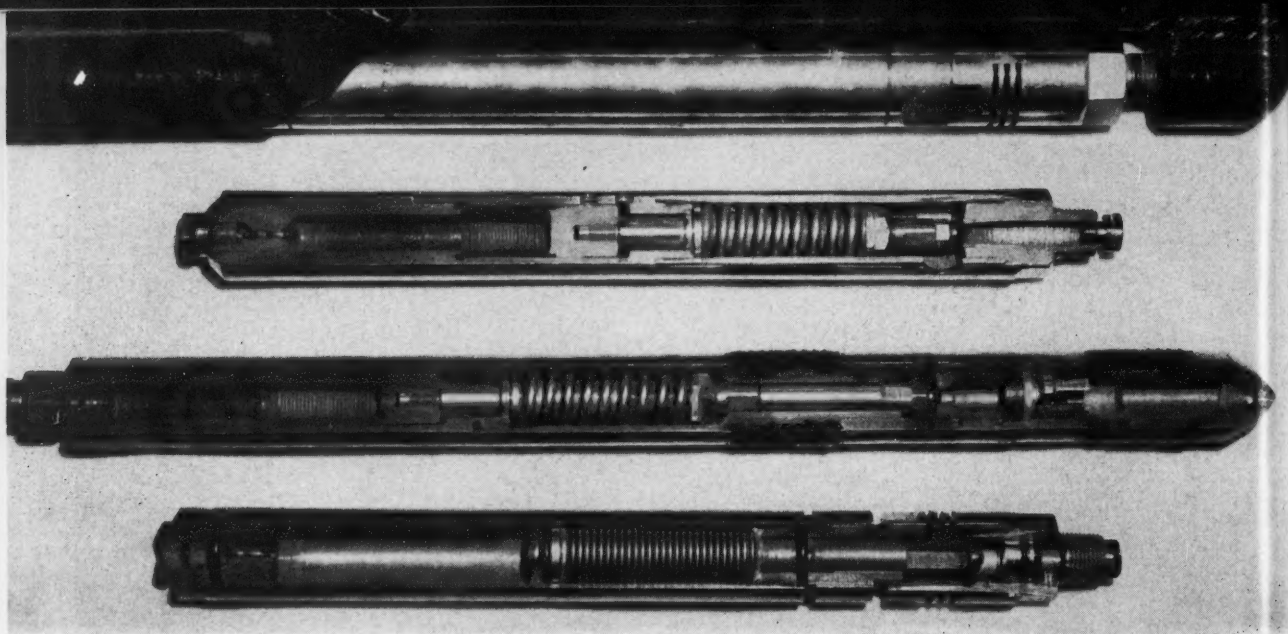


Figure 1—Cutaway sections of various flow valves and mandrel and valve assembly

## Laboratory and Field Tests on

# Titanium for Oil Field

**T**ITANIUM METAL production increased rapidly after the beginning of World War II. Quality of the metal and alloys has been upgraded substantially and the areas of use broadened significantly.<sup>1</sup> Furthermore, because of continued emphasis on improving production facilities and processes, the base price has been lowered to a point where the material no longer can be excluded as a corrosion-control metal solely on a price basis.

Estimates of the cost of corrosion to the producing phase of the petroleum industry includes many factors which cannot be fully evaluated. The annual cost of corrosion in production of sour crude oil alone amounts to \$35 million per year,<sup>2</sup> while replacement costs for equipment in gas-lift wells amounts to \$16,000,000 annually.<sup>3</sup> A reasonable estimate of the total cost of corrosion to the producing phase of the industry, including replacement and preventive measures is \$70,000,000 per year.

This study was designed to determine the suitability of titanium in several applications in oil production equipment and to estimate its probable use in production techniques to be developed in the future. The investigation was limited to two principal artificial lifting methods, gas lift and plunger pumps and their related problems and included several field tests.

## Investigations Conducted Under This Research Project

The major field of study concerned the use of titanium in gas lift valves and as ball and seat combinations in oil well pumps. Metals used in such equipment are principally stainless steels, Monel, Hastelloys. Corrosion and erosion of metal are primary causes of failure of both types of equipment.

Corrosion problems encountered in flow of fluids in tubing and casing must, of necessity, be related to the corrosion experienced in either gas lift equipment or in pumping operations. Likewise, very serious erosion problems arise when fluid flow either alone or bearing finely divided sand particles, reaches the extremely high velocities prevalent in many gas wells.

Completion techniques require the flow of drilling fluids (clay suspensions carrying varying quantities of sand and rock cuttings) through small apertures in valves used to circulate or remove such fluids from the hole and thus induce initial flow of oil and/or gas in a well. Again, erosion may occur and damaged equipment result. Studies simulating such conditions were carried out in the laboratory.

## Gas Lift Valve Studies

Many design variations are found in gas lift valves now in use in producing oil. Essentially the purpose of the valve is to provide a means for introducing gas into a fluid column, thus lightening the column and because of decreased hydrostatic pressure of the over-all fluid column, maintain flow of reservoir fluids to the surface.

★ Revision of a paper titled "Titanium—Use in Oil Production Equipment" presented at the 17th Annual Conference, National Association of Corrosion Engineers, Buffalo, N. Y., March 13-17, 1961.



F. W. Jessen  
and  
Ricardo J. Molina

University of Texas  
Austin, Texas

#### Abstract

Laboratory and field tests are reported for titanium parts for gas lift valves and down-hole oil well pumps. While titanium performed well in the laboratory tests using aerated fluids, and did well in field tests of gas lift wells, similar trials in wells pumping sour crude oil well showed titanium to be inferior to normally used materials. Authors conclude titanium is suitable for use in gas lift valves and could be competitive to presently used materials at a lower price.

They conclude titanium is not suitable for use in oil well pumps, but might perform better if hardened. It also is at a competitive disadvantage to commonly used materials costwise.

While titanium is cathodic to materials commonly used in oil wells, no marked corrosion was attributed to this property after exposure of coupon sets in a producing well. Titanium was found resistant to abrasion by sand-laden aerated oil well fluids in laboratory tests.

6.3.15, 8.4.3

**TABLE 1—Effect of Impingement on Corrosion of J-55 Steel, Titanium, Monel, Nickel and Stainless Steel 316**

Corrosive environment.....ASTM Standard Brine, Saturated with Air.  
Injected medium.....Air  
Orifice diameter..... $\frac{1}{4}$  inch.  
Distance between orifice and specimen... $\frac{1}{4}$  inch.  
Duration of test.....3 days.

Trial	Differential Pressure psi	Metal	Immersed, Normal Flow		Immersed, Subject To Impingement		Appearance & Remarks
			Wt. Loss, gm	Corrosion Rate mpy	Wt. Loss, gm	Corrosion Rate mpy	
1	100	Monel	0	0			Smooth
		Monel			0.0017	33.7	Smooth
2	100	Nickel	0	0			Smooth
		Nickel			0	0	Clean
3	100	J-55			0.2084	42.15	(1)
		J-55	0.0898	18.18			Uniformly Corroded
4	100	J-55			0.1989	40.20	(1)
		J-55	0.0879	17.76			Uniformly Corroded
5	100	Titanium			0	0	Smooth
		Titanium	0	0			Smooth
6	100	Monel	0	0			Smooth
		Monel			0	0	Smooth
7	100	316 SS	0	0			Smooth
		316 SS			0	0	Smooth

(1) Specimen corroded uniformly with the exception of area under impingement.

**TABLE 2—Effect of Impingement on Corrosion of J-55 Steel, Titanium, Monel, and Stainless Steel 316**

Same conditions as Table 1, except: Orifice-to-specimen distance,  $\frac{3}{8}$  inch; test duration, 2 days.

Trial	Differential Pressure psi	Metal	Immersed, Normal Flow		Immersed, Subject To Impingement		Appearance & Remarks
			Wt. Loss, gm	Corrosion Rate mpy	Wt. Loss, gm	Corrosion Rate mpy	
1	100	J-55	0.1253	38			Uniformly Corroded
		J-55			0.1992	60.3	(1)
2	100	J-55	0.1304	39.60			Uniformly Corroded
		J-55			0.1989	60.2	(1)
3	100	Monel	0	0			Smooth
		Monel			0	0	Smooth
4	100	Monel	0	0			Smooth
		Monel			0	0	Smooth
5	100	Titanium	0	0			Smooth
		Titanium			0	0	Smooth
6	100	316 SS	0	0			Smooth
		316 SS			0	0	Smooth
7	100	Titanium	0	0			Smooth
		Titanium			0	0	Smooth

(1) Uniformly corroded except for area of direct impingement by air.

# Pump and Valve Parts\*

Several different types of valves are illustrated in Figure 1. The most vulnerable parts of the gas lift valve are the ball and seat and the port. Attack by corrosive fluids on either of these parts or on the spring of the valve will sooner or later result in ineffective operation.

Tests were run to determine corrosion rates under varying conditions for eight separate metal specimens at the same time. A polymethyl methacrylate, (Lucite) container was used in which coupon spacing and circulation rate of fluids could be controlled. Circulation of fluid was through two separate chambers each having four 3-inch square compartments, 12 inches in height. A tight fitting top, slightly recessed to provide for a soft rubber gasket, made the container fairly tight and a condenser on top minimized vapor losses. The metal test pieces were held vertically by a slotted plastic base placed in the bottom and permitted any desired spacing from

the orifice. Air or natural gas was passed through the orifices to create turbulence and cause direct impingement on the test coupons, thus simulating action at the point of entry of gas in a gas lift valve.

The specimens were polished with a 50-grind sand paper on a sanding wheel and finished with a 300-fine emery cloth, numbered and stored in a desiccator. They were weighed to four significant figures before use. At the completion of a test run, the specimens were washed with soap and water, dipped in a dilute

solution of HCl, rinsed with water, placed in an acetone bath, dried and weighed.

#### Results of Gas Lift Valve Studies

Results of laboratory studies indicate good corrosion resistance of titanium. Tables 1 through 6 show results of tests under varying conditions of exposure to direct impingement. Fluid velocities of 0.3 to 3 feet per second were employed using air and natural gas to create the jet action.

(Continued on Page 18)



# Top guns in your anti-corrosion arsenal

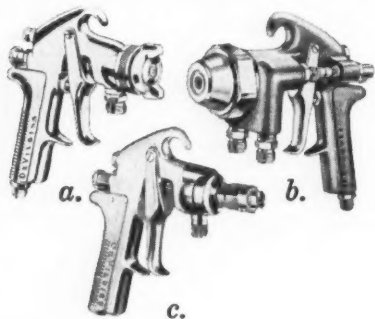
## Pump and Valve Parts

(Continued From Page 17)

All weight losses determined were used to compute an average penetration rate in mils per year assuming corrosion to be uniform. On samples positioned close to the jet, distinct pitting action was observed on steel plates as shown in Figure 2.

Titanium was not affected by exposure to salt brines either with or without impingement caused by injection of natural gas or air. Furthermore, none

When you're waging your battle against corrosion, it will pay you to have DeVilbiss spray guns for full covering coatings that provide greater protection on any surface—flat, recessed, irregular or angular. Application is far faster than any contact application method.



**STANDARD DEVILBISS SPRAY GUNS** (a.) handle practically any pourable protective finish. May be used with portable hot-spray outfit that puts on fuller covering films with minimum overspray. **CATALYST GUN** (b.) with hot-spray outfit sprays urethane foams, other inert plural-component protective materials. **AIRLESS SPRAY GUN** (c.) used in conjunction with portable outfit, produces large spray pattern for ultra-fast coverage of broad areas. For full details on our complete line of spray equipment, write: The DeVilbiss Company, Toledo 1, Ohio.



**TABLE 3—Effect of Impingement on Corrosion of J-55 Steel, Titanium, Monel, Nickel and Stainless Steel 316**

Same conditions as Table 1 except: Orifice-to-specimen distance 1 1/4 inches; test duration, 2 days.

Trial	Differential Pressure psi	Metal	Immersed, Normal Flow		Immersed, Subject To Impingement		Appearance & Remarks
			Wt. Loss gm	Corrosion Rate mpy	Wt. Loss, gm	Corrosion Rate mpy	
1	100	J-55	0.0361	41.3			Uniformly Corroded
		J-55			0.1362	10.9	"
2	100	J-55	0.0404	36.10			"
		J-55			0.1189	12.26	"
3	100	Titanium	0	0			Smooth & Bright
		Titanium			0	0	"
4	100	Titanium	0	0			"
		Titanium			0	0	"
5	100	Monel	0	0			"
		Monel			0	0	"
6	100	Monel	0	0			"
		Monel			0	0	"
7	100	316 SS	0	0			"
		316 SS			0	0	"
8	100	Nickel	0	0			"
		Nickel			0	0	"

**TABLE 4—Effect of Impingement on Corrosion of Steel, Titanium, Nickel and Monel**

Corrosive environment.....Crude oil and brine from Magnet Withers Field, Wharton County, Texas, saturated with air.  
Injected medium.....Air.  
Orifice diameter.....1/16 inch.  
Distance between orifice and specimen.....3/4 inch.  
Duration of test.....2 days.

Trial	Volume Percent		Differential Pressure psi	Metal	Immersed, Normal Flow		Immersed, Subject To Impingement		Appearance & Remarks
	Oil	Water			Wt. Loss gm	Corrosion Rate mpy	Wt. Loss gm	Corrosion Rate mpy	
1	8	92	150	J-55	0.0642	26.00			Corroded uniformly
				J-55			0.2487	101.0	(1)
2	8	92	150	J-55	0.0597	24.90			Corroded uniformly
				J-55			0.2490	104.0	(1)
3	8	92	150	J-55	0.0637	26.50			Corroded uniformly
				J-55			0.2500	104.0	(1)
4	8	92	150	Titanium	0	0			Smooth
				Titanium			0	0	"
5	8	92	150	Titanium	0	0			"
				Titanium			0	0	"
6	8	92	150	Nickel	0	0			"
				Nickel			0	0	"
7	8	92	150	Monel	0	0			"
				Monel			0	0	"

(1) Uniformly corroded except for area subject to direct attack of air stream.



of the materials tested showed any weight loss, when natural gas was used. Penetration of the surface by pitting action was absent even in the case of coupons placed at  $\frac{1}{4}$ -inch from the ori-

fice. On the other hand, no distinct patterns of corrosion were noted beyond a distance of one inch from the orifice when pressure differentials did not ex-

(Continued on Page 20)

**TABLE 5—Effect of Impingement on Corrosion of J-55 Steel and Titanium**

Corrosive environment.....Crude oil from Prentice Field, Yoakum County, Texas, and ASTM brine, saturated with air.  
Injected Medium.....Air.  
Orifice diameter..... $\frac{1}{16}$  inch.  
Distance between orifice and specimen.....1 inch.  
Duration of test.....2 days.

Trial	Volume Percent		Differential Pressure psi	Metal	Immersed, Normal Flow		Immersed, Subject To Impingement	
	Oil	Water			Wt. Loss gm	Corrosion Rate mpy	Wt. Loss gm	Corrosion Rate mpy
1	50	50	150	J-55	0	0		
	50	50	150	J-55			0	0
2	50	50	150	J-55	0	0		
	50	50	150	J-55			0	0
3	50	50	150	Titanium	0	0		
	50	50	150	Titanium			0	0
4	40	60	150	J-55	0.0634	19.25		
	40	60	150	J-55			0.0732	22.2
5	40	60	150	Titanium	0	0		
	40	60	150	Titanium			0	0
6	30	70	150	J-55	0.0843	25.65		
	30	70	150	J-55			0.0958	29.0
7	30	70	150	Titanium	0	0		
	30	70	150	Titanium			0	0
8	20	80	150	J-55	0.0998	30.3		
	20	80	150	J-55			0.1969	59.75
9	20	80	150	Titanium	0	0		
	20	80	150	Titanium			0	0

**TABLE 6—Effect of Impingement on Corrosion of J-55 Steel and Titanium**

Corrosive environment.....Crude oil and brine from Magnet Withers Field, Wharton County, Texas, saturated with air.  
Injected medium.....Air.  
Orifice diameter..... $\frac{3}{64}$  inch.  
Distance between orifice and specimen..... $\frac{1}{16}$  inch.  
Duration of test.....5 days.

Trial	Volume Percent		Differential Pressure psi	Metal	Immersed, Normal Flow		Immersed, Subject To Impingement	
	Oil	Water			Wt. Loss gm	Corrosion Rate mpy	Wt. Loss gm	Corrosion Rate mpy
1	50	50	150	J-55	0.0002	0.0238		
	50	50	150	J-55			0.0	0.0
2	50	50	150	J-55	0.0001	0.0125		
	50	50	150	J-55			0.0	0.0
3	50	50	150	Titanium	0.0	0.0		
	50	50	150	Titanium			0.0	0.0
4	40	60	150	J-55	0.0724	8.8		
	40	60	150	J-55			0.1028	9.98
5	40	60	150	Titanium	0	0		
	40	60	150	Titanium			0	0.0
6	30	70	150	J-55	0.0925	11.23		
	30	70	150	J-55			0.1502	18.24
7	30	70	150	Titanium	0	0		
	30	70	150	Titanium			0	0
8	20	80	150	J-55	0.0930	11.3		
	20	80	150	J-55			0.1759	21.30
9	20	80	150	Titanium	0	0		
	20	80	150	Titanium			0	0

## Technical Topics

### Scheduled for December

Crash Repair Program to Control Serious Pitting Corrosion on Process Tanks

Cell Apparatus Checks Resistivity of Nitrogen Tetroxide Fuel to Control Corrosion on Missiles

Corrosion Control Advantages of Polyamide-Epoxy Coatings

Laboratory Tests Show Resistance Properties of Urethane Coatings



## TECHNICAL REPORTS

on

### HIGH PURITY WATER CORROSION

On sales to Texas addresses, add 2% tax.

Symposium on Corrosion by High Purity Water by Committee T-3F on High Purity Water which includes:

Introduction to Symposium on Corrosion by High-Purity Water by John F. Eckel.

Corrosion of Structural Materials in High-Purity Water by A. H. Roebuck, C. R. Breder and S. Greenberg.

Corrosion Engineering Problems in High-Purity Water by D. J. DePaul.

The Importance of High-Purity Water Data to Industrial Applications by W. Z. Friend. Per Copy \$3.75

Symposium on Corrosion by High Purity Water. Five Contributions to the Work of NACE Technical Committee T-3F on High Purity Water. Pub. 57-22.

Measurement of Corrosion Products in High Temperature, High Pressure Water Systems by A. S. Sugalski and S. I. Williams.

Corrosion of Aluminum-Nickel Type Alloys in High Temperature Aqueous Service by F. H. Krenz.

Corrosion of Aluminum in High Purity Water by R. J. Lobsinger and J. M. Atwood.

The Storage of High Purity Water by Richard R. Dieck.

Water Conditions for High Pressure Boilers by D. E. Voyles and E. C. Fiss. Per Copy \$6.50

Symposium on Corrosion by High Purity Water. Four Contributions to the Work of NACE Tech. Comm. T-3F on High Purity Water. Pub. 58-13. Per Copy \$5.50

Corrosion Behavior of Zirconium-Uranium Alloys in High Temperature Water, by W. E. Berry and R. S. Peoples.

Corrosion and Water Purity Control for the Army Package Power Reactor by R. J. Clark and A. Louis Medin.

Removal of Corrosion Products from High Temperature, High Purity Water Systems with an Axial Bed Filter by R. E. Larson and S. L. Williams.

Some Relations Between Deposition and Corrosion Contamination in Low Make-up Systems for Steam Power Plants by E. S. Johnson and H. Kehmna.

Remittances must accompany all orders for literature the aggregate cost of which is less than \$5. Orders of value greater than \$5 will be invoiced if requested. Send orders to National Association of Corrosion Engineers, 1061 M & M Bldg., Houston, Texas. Add 75¢ per package to the prices given above for Book Post Registry to all addresses outside the United States, Canada and Mexico.

## NATIONAL ASSOCIATION OF CORROSION ENGINEERS

1061 M & M Bldg. Houston 2, Texas



## Pump and Valve Parts

(Continued From Page 19)

ceed 100 psi. At closer range, however, considerable variation was observed with the aerated solutions.

The impingement effect noticed on the steel specimens is caused by a more active or localized intensity of corrosion of the metal. Rapid removal of corrosion products enhances the rate of attack. A "sunburst" appearance describes the streaked lines extending radially from the center of attack. Samples spaced at distances of  $\frac{3}{4}$  inch from the orifice did not show pronounced attack and all tests at spacings greater than  $\frac{3}{4}$  inch, regardless of orifice size or operating pressure, showed no pitting.

If extraneous materials such as sand, drilling mud, scale, or mineral deposits are absent in the well fluid, the injection of clean natural gas should cause no

erosion damage to either the valve or tubing. Corrosion may be enhanced by galvanic action, however. In this connection, attention is called to the field data obtained on tests in a well in the Magnet-Withers Field, Wharton County, Texas.

### Erosion Resistance of Titanium

Loss of metal by erosion is influenced by fluid composition, the kind and amount of abrasive material present, and the velocity and direction of flow across the metal surface. In gas lift valve equipment the variables are (1) total amount and relative proportion of oil, gas and water produced; and (2) kind and amount of sand, or fine silt, drilling fluid (during washing-in operations), scale or mineral deposit. Since the production rate determines the average flow velocity in the tubing, comparable rates were used in laboratory tests. Turbulent flow conditions prevail in gas lift wells and additional agitation occurs at the entry point of the gas.

Erosion resistance tests were conducted using the equipment shown in Figure 3. The test specimen was mounted on nonconducting plastic (Figure 4). Fluid velocities were maintained with a centrifugal pump and sharp changes in velocity and direction of flow were made by substituting different sized ells and nipples in the system. Data reported are at flow rates of 10 and 40 fps. The circulating fluids used are (1) sour crude oil from the Prentice Field,

Yoakum County, Texas (2) an 80 percent salt water-20 percent crude oil mixture, (3) the same mixture with 1.2 percent sand of 150-200 mesh size. Results in Table 7 show substantially more metal was lost from J-55 steel than from titanium. Adaptability of titanium to all parts of flow valves is indicated.

### Field Tests of Gas Lift Valves and Titanium Specimens

Coupons of titanium, J-55 and N-80 grades steels and 9 percent nickel-steel were installed in a well in the Magnet Withers Field, Wharton County, Texas. The rack carrying the individual metal coupons ( $\frac{1}{8}$  by  $\frac{5}{8}$  by  $2\frac{1}{2}$  inches) was placed at the 3300-foot level in the tubing of the well being tested. Total depth of the well was 5500 feet.

Gas lift valves were placed at intervals, the lowest being at 3700 feet. The position of the test rack thus may be seen to be just above the lowest (operating) valve. Because all the fluid flow passed over the specimens, only the effect of direct jet action opposite the operating gas lift valve would not be included in the over-all corrosion experienced by the test pieces. The holder accommodated 12 separate metal specimens several of which were "coupled" with metal washers rather than separated by the insulating fiber washers. Short-coupled test pieces were joined through a washer and bolt at the lower end through the rack and a washer at the top end (Figure 5).

The well was producing on gas lift at a daily production of 27 barrels of oil and 365 barrels of salt water. Formation gas/oil ratio was 926 cu ft per barrel. Two test periods were completed, the first 23 days from July 16 to August 8, 1957 and the second 22 days from August 8 to August 30, 1957. Data are reported in Tables 8 and 9.

Titanium showed excellent resistance to attack by the salt water and was substantially better than the 9 percent nickel-steel specimens. All steel samples exhibited high susceptibility to attack, which was enhanced when coupled to titanium. In case of the J-55 grade steel, "short-coupled" coupons showed an increased loss of 50 percent while no difference was found for the "long-coupled" coupons. For the N-80 grade steel, a 100 percent increase in the corrosion rate occurred for the "short-coupled" samples while the rate of attack for the "long-coupled" samples and the uncoupled metal was practically identical.

Because of the marked difference noted in the field tests between the corrosion rate of N-80 grade over J-55 grade steel when coupled to titanium, the electrochemical potential of these two steels, P-110 grade steel and titanium was measured in brine using a standard saturated calomel electrode. The data of Table 10 show little reason for increased galvanic action supposedly responsible for the greater loss of metal from the N-80 steel coupled coupons.

A wire line retrievable gas lift valve with the nose, check valve, check disc and fishing neck machined of titanium bar stock was run in a well in the Gohlke Field, Dewitt and Victoria Counties, Texas. This installation was put

(Continued on Page 22)

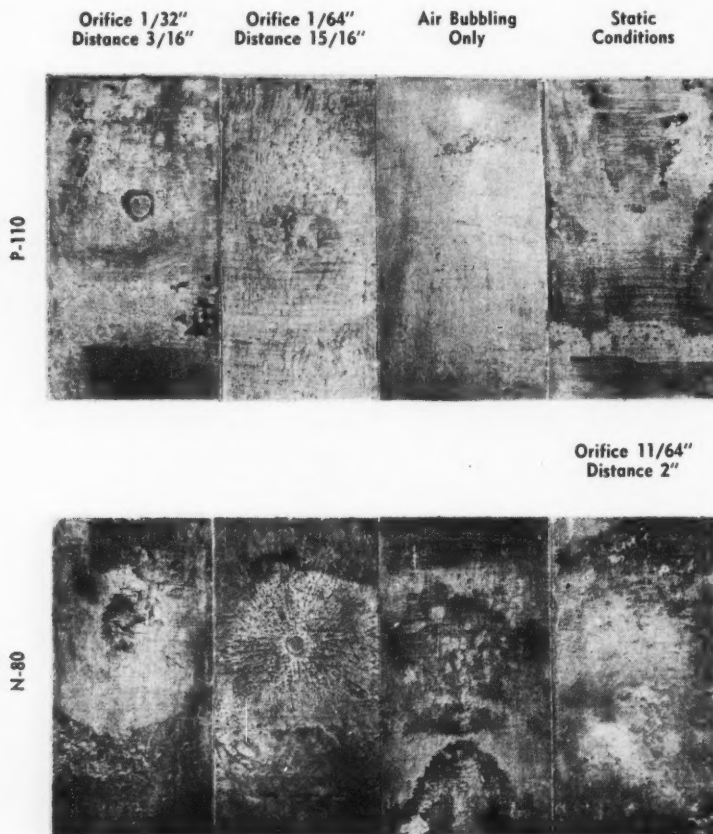


Figure 2—Pattern of corrosion attack on various steels subject to fluid impingement caused by air jet.



# TYZIN ...a new zinc-rich primer by Stoneware

Tyzin is a self-curing sacrificial metal primer offering excellent resistance, with or without a top coat, to organic and inorganic solvents, fresh or salt water, oils and greases.

A 2-3 mil film (obtainable in a single application) provides an excellent primed surface for all standard Tygon vinyl top coats or for Tygon Series "E" Epoxy.

Tyzin consists of a modified lacquer base into which is blended metal zinc powder to form a blended solution of better than 57% total solids by weight.

Applied by conventional brush or spray application, Tyzin air dries within 15 minutes to a rain and weather-resistant coating. It can be top-coated with any suitable top coat within a few hours.

With excellent adhesion to properly prepared surfaces, Tyzin proves a low-cost self-sacrificing metal primer for top protection from galvanic attack.

For detailed technical data write  
Coatings and Linings Division, U. S.  
Stoneware, Akron 9, Ohio.



**U. S. STONEWARE**

**AKRON 9, OHIO**



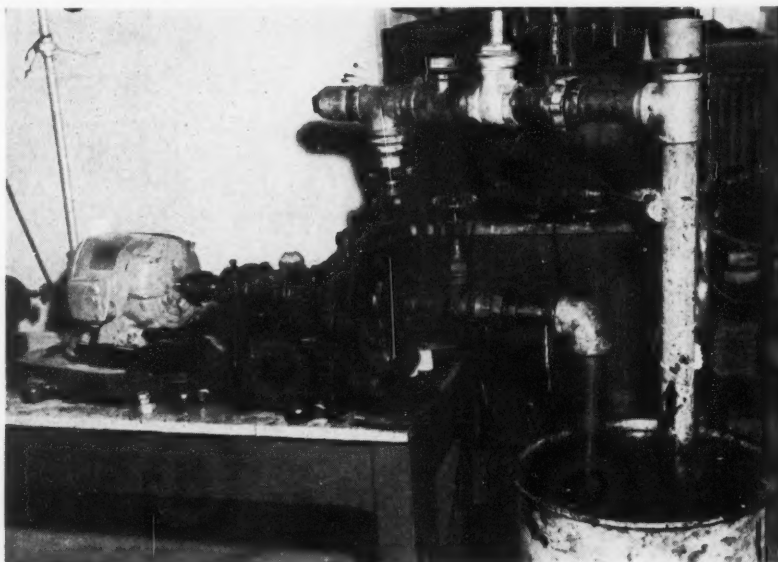


Figure 3—Equipment assembly for fluid erosion tests.

## Pump and Valve Parts

(Continued From Page 20)

in service in October 23, 1957, and was removed in March, 1958, for inspection. Careful examination at that time revealed no corrosion of the titanium. The valve was rerun and operated successfully until August 18, 1958 when it was removed again. The titanium remained free of any corrosion or abrasion damage. Length of field service was slightly less than 10 months.

### Titanium as Ball and Seat Combination in Oil Well Pumps

Application of titanium to oil well pumps seems exceptionally appropriate because of its excellent corrosion resistance to brines and hydrogen sulfide. Its density makes it particularly attractive for use in ball valves. Further tests showed a high degree of resistance to erosion, so its use as ball valve seats also appeared appropriate. Inasmuch as failure of these parts is the cause of probably 85 percent of pump trouble, extension of service life would be valuable.

### Laboratory Investigation

Laboratory study of ball and seat combinations was started after failure of a set of titanium balls and seats placed in a Caldwell County, Texas well. Evidence of pitting and chipping of the ball was noted and severe fluid cutting or erosion was observed in the seat. Failure of both ball and seat were not considered characteristic so laboratory tests were undertaken in an effort to duplicate results of field tests.

The apparatus consisted of two sections of Lucite tubing joined to incorporate the seat and ball. Figure 6 shows the assembled unit in operation while

the component parts are illustrated in Figure 7. Tests were run for two months with  $H_2S$  brine and natural gas and for 30 days with brine and air. No weight loss occurred in any of the materials tested: Haystellite, Hastelloy, Monel or titanium. The titanium ball was discolored but no erosion or deformation of the seat was observed. Because operating pressure was atmospheric, impact force was low. However, the number of blows per minute was 5 to 10 times that encountered normally in the field. That is, while there are 20 movements of the ball from its seat per minute in pumping at 20 strokes per minute, from 100 to 200 such actions were obtained by the laboratory procedure followed.

### Field Tests of Titanium Ball And Seat Combinations in Pumping Wells

Titanium balls and seats were run in a number of wells in Caldwell and Guadalupe Counties, Texas, which produce "sour" crude oil, containing  $H_2S$ , with large volumes of salt water. The salt water has a total dissolved salt content of 25,000 ppm, primarily NaCl but with sufficient calcium and magnesium to cause carbonate deposits.

Unusual conditions existed in the B-19 well which made it extremely hard on balls and seats. From Figure 8 the fluid cutting action is easily discernible over much of the beveled edge of the seat. Actually deeper cut-out areas existed in the Hi-Chrome and the Haynes Stellite seats examined than in the titanium, although all were damaged severely. Additional tests in the B-19 well were not possible because it was abandoned.

Results of the entire testing program are shown in Figure 9. The following comments refer to tests recorded in that figure.

Valves were run in to the AM-5 well on April 3 and removed on August 14, 1958. It was reported seats had been run on both sides, so although the time was a little over four months, an average of two months' service was considered. The balls were said to be in bad condition, scratches and chips appearing over the surface. Other metals in this well had lasted 2 to 3 months be-

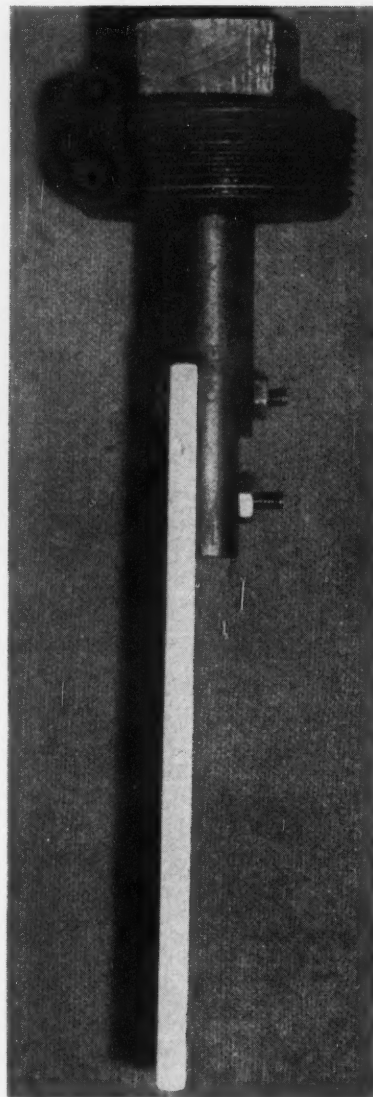


Figure 4—Mounting of coupons used in erosion studies.

fore replacement became necessary so, even though titanium was damaged its record was comparable to that of other commonly used materials.

In the B-11 well, a traveling valve assembly only was installed on March 21 and removed on May 1, 1958. No failure occurred in this valve set although the ball was scratched. Average length of service for balls and seats in this well was one year and three months, so no conclusions can be drawn as to the likelihood of equivalent performance. This test was not considered representative.

While performance of titanium in the H-15 well is exceptionally good, only about half the service life of competing materials is indicated in the P-13 and T-27 wells. Average life of the titanium balls and seats in all tests in Figure 9 was 123 days for traveling valves and 160 days for standing valves. This compares to 236 days and 244 days respectively for other metals used. The figures do not include data from the H-15 well. In every instance, inspection revealed

(Continued on Page 24)



*when  
corrosion  
is eating  
up the  
profits...*

*think  
Tube-Kote®*

The cost of replacing tubing can be almost prohibitive in highly corrosive fields and offshore wells. These replacement costs may be significantly lowered by using Tube-Kote plastic coatings to protect metal from corrosion. Tube-Kote coatings are recommended for protection of storage tanks, flow lines and wherever loss of equipment due to corrosion adds to operating cost. Performance proved the world over for more than 20 years, Tube-Kote coatings are also recommended to prevent paraffin deposition.

Tube-Kote sales engineers will show you case histories of increased profits after using Tube-Kote coatings. Tube-Kote research is available to you in solving your own unusual corrosion problems. Think Tube-Kote to stop corrosion and increase profits.

TUBE-KOTE RESEARCH AND SUPERIOR METHODS BRING YOU MORE DURABLE COATINGS AND FASTER SERVICE . . . AT LOWER COST!



Service Mark Reg. U. S. Pat. Off.

OUR 22ND YEAR... THE INDUSTRY PIONEER

**TUBE-  
KOTE®**

P. O. Box 20037 • Houston 25, Texas

Branch Plants:

Harvey, Louisiana

Midland, Texas

Edmonton, Alberta, Canada



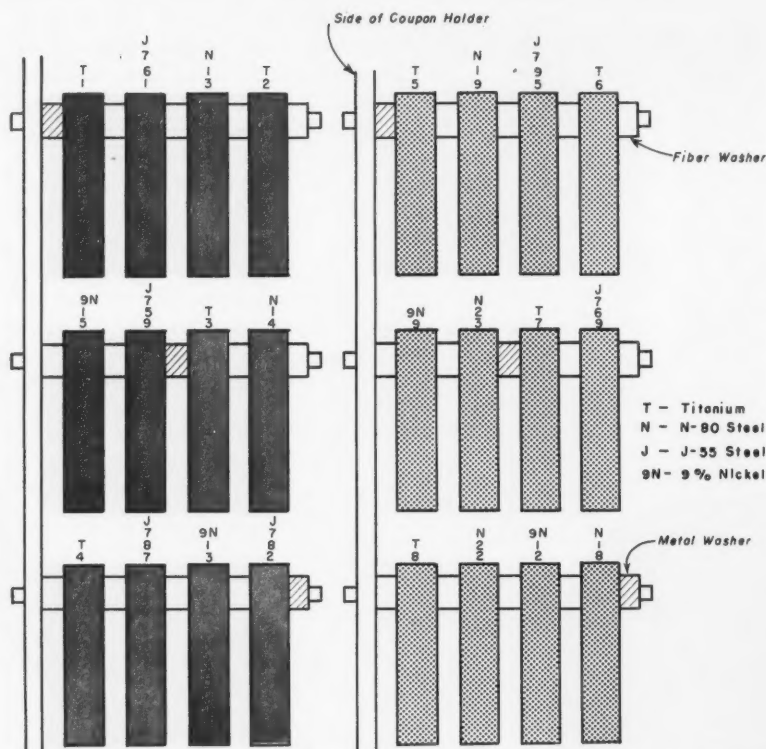


Figure 5—Position of coupons on test rack run in B-27 well, Magnet Withers Field, Texas. Set One on left were installed July 16, 1957, withdrawn August 8, 1957. Set Two on right were installed August 8, 1957, withdrawn August 30, 1957.

## Pump and Valve Parts

(Continued From Page 22)

small chips broken from the balls and seats with varying degree of fluid cutting discernible on the face of the seats. One seat was so badly cut that the ball became lodged, necessitating pulling the well.

Because excellent resistance to corrosion attack in other tests was exhibited by titanium, it is postulated that hardening of the metal might provide satisfactory ball and seat surfaces.

(Continued on Page 26)

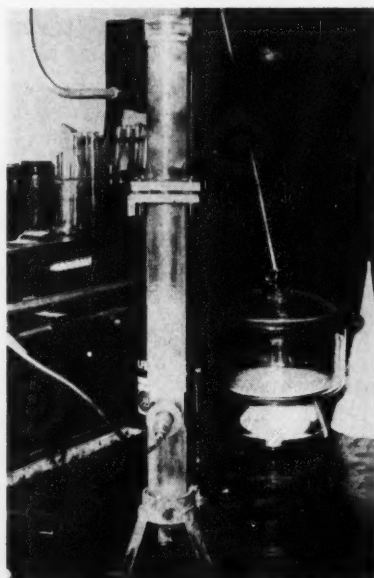


Figure 6—Laboratory set-up for testing ball and seat combinations.

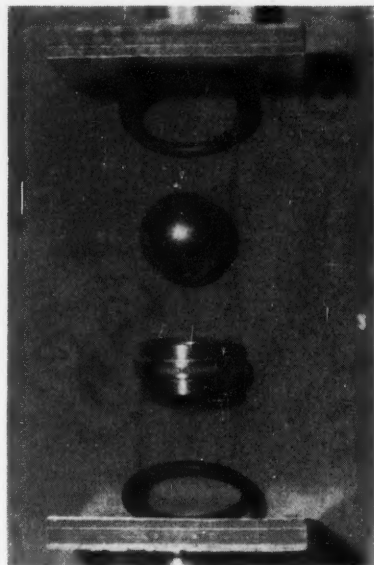
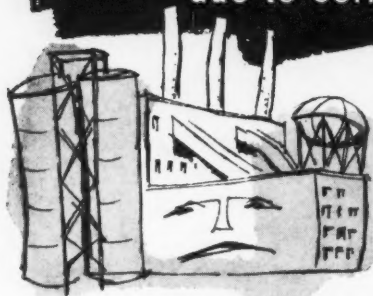


Figure 7—Detailed arrangement of ball valve in plastic holder.

**HOW MUCH** did your plant contribute to the \$6 BILLION LOSS due to corrosion?



**VALDURA  
VAL-CHEM  
COATINGS  
STOP** costly corrosion

Your plant's share of the tremendous loss to corrosion last year could have been stopped with one of Valdura's Val-Chem chemically-resistant coatings. Remember—no one coating can solve all the problems. That's why Valdura offers you a *complete line* to fit every need—the new,

field-tested Val-Chem Coatings. The assistance of Valdura's nationwide force of field representatives—experts in corrosion control—is at your service. How can Val-Chem Coatings stop corrosion in *your* plant? Write today on your letterhead for a prompt solution!

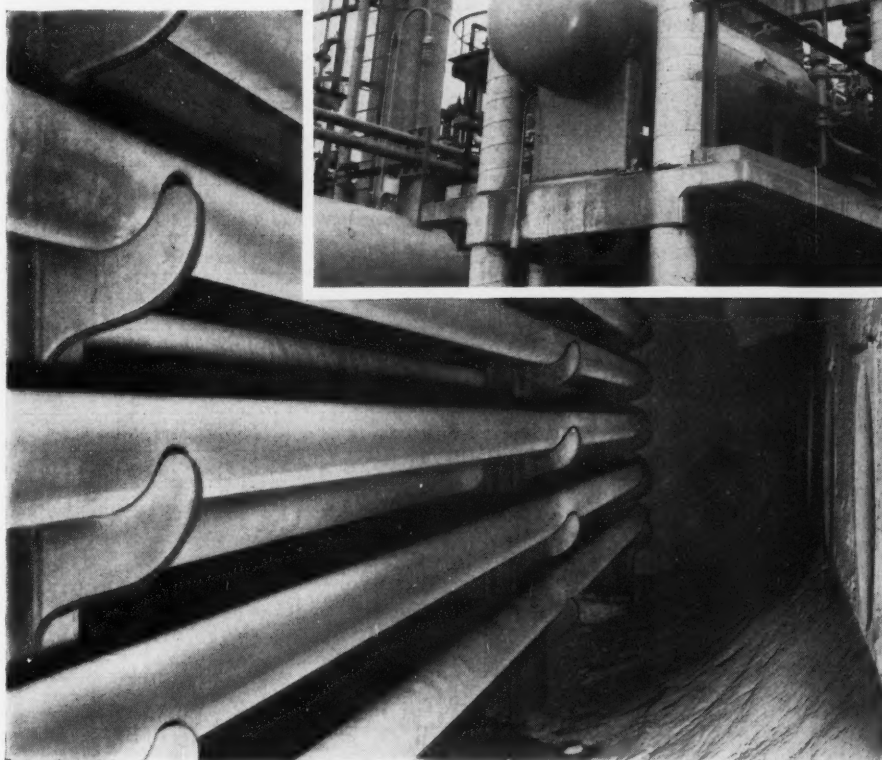
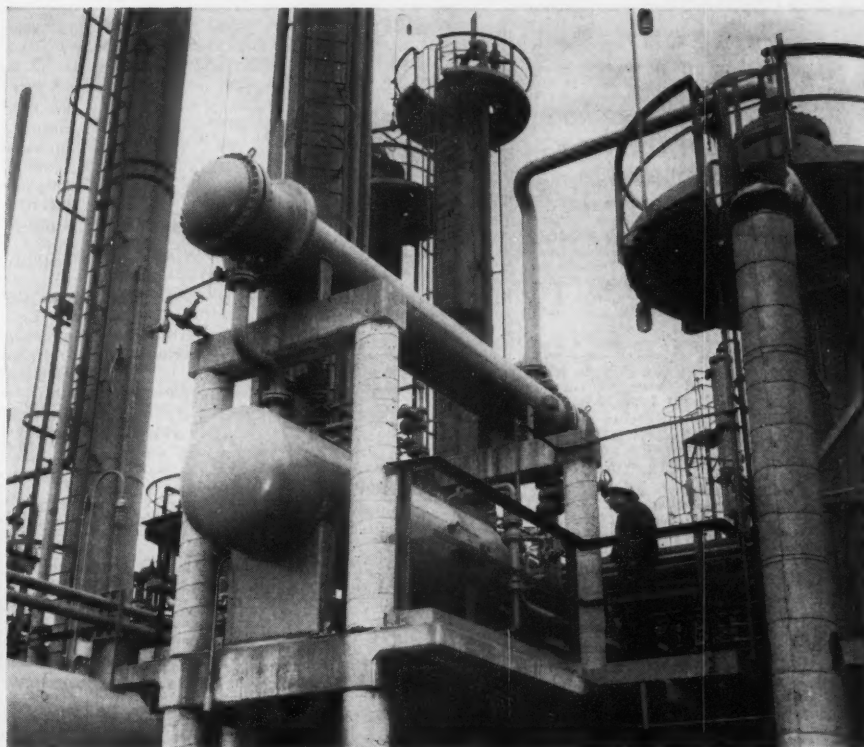


**VALDURA HEAVY DUTY PAINT DIVISION**  
AMERICAN-MARIETTA CO., CHICAGO 11, ILL



**STEP 1** →

**The production of ethylene dichloride.** Ethylene and chlorine are blended and charged to the reactor. Reaction products pass through a MONEL Alloy 400 condenser made up of a series of 1 inch tubes, 193 inches long.

**STEP 2**

**The cracking of ethylene dichloride.** Ethylene dichloride enters the direct-fired cracking furnace as a dry vapor. The furnace contains INCONEL Alloy 600 extruded tubes 3 3/4 inches in diameter and 15 feet long. Vinyl chloride is produced in these tubes through the thermal cracking of ethylene dichloride. The tubes, tube return bends, and the inlet and outlet flanges are made of INCONEL Alloy 600.

## How 2 Nickel alloys protect vinyl chloride plant against corrosion by HCl and Cl<sub>2</sub>

At American Chemical Corporation's new facility at Long Beach, California, MONEL\* Alloy 400 and INCONEL\* Alloy 600 are helping to increase efficiency and production in this first vinyl chloride monomer plant on the West Coast.

INCONEL alloy 600 and MONEL alloy 400 have excellent resistance to corrosion by hydrogen chloride and chlorine. Both materials combat all types of chloride attack—general corrosion, stress-corrosion cracking, pitting, and

erosion-corrosion—at elevated temperatures.

The production of vinyl chloride is only one of many possible applications for MONEL nickel-copper alloys and INCONEL nickel-chromium alloys. If you would like to know more about these corrosion resistant materials, write for our technical bulletins T-5 and T-7. If

you need additional help in solving corrosion problems, write to us. Our technical service staff will be glad to assist you.

\*Registered trademarks

**HUNTINGTON ALLOY PRODUCTS DIVISION**  
The International Nickel Company, Inc.  
Huntington 17 West Virginia



# HUNTINGTON ALLOYS





## TECHNICAL REPORTS on REFINING INDUSTRY CORROSION

On sales to Texas addresses  
add 2% tax.

**T-8 High-Temperature Hydrogen Sulfide Corrosion of Stainless Steel—A Contribution to the Work of NACE Tech. Group Committee T-8 on Refinery Industry Corrosion**, by E. B. Backensto, R. E. Drew, J. E. Prior and J. W. Sjöberg. Pub. 58-3, Per Copy \$1.50.

**T-8 Compilation and Correlation of High Temperature Catalytic Reformer Corrosion Data—A Contribution to the Work of NACE Tech. Group Committee T-8**, by G. Sorell. Pub. 58-2, Per Copy \$3.00.

**T-5B-2 Effect of Sulfide Scales on Catalytic Reforming and Cracking Units. Part 1—Metallographic Examination of Samples From a Catalytic Reforming Unit. Part 2—Intergranular Corrosion of 18-8 Cr-Ni Steel as a Result of Hydrolysis of Iron Sulfide Scale. A Contribution to the Work of NACE Task Group T-5B-2 on Sulfide Corrosion at High Pressures and Temperatures in the Petroleum Industry.** Per Copy \$1.50.

**T-5B-2 Collection and Correlation of High Temperature Hydrogen Sulfide Corrosion Data—A Contribution to the Work of NACE Task Group T-5B-2 on Sulfide Corrosion at High Temperatures and Pressures in the Petroleum Industry: From M. W. Kellogg Co., New York by G. Sorell and W. B. Hoyt.** Pub. 56-7. Per Copy \$5.50.

**T-5B-2 High Temperature Hydrogen Sulfide Corrosion in Thermoform Catalytic Reformers—A Contribution to the Work of NACE Task Group T-5B-2 on Sulfide Corrosion at High Temperatures and Pressures in the Petroleum Industry: From Socony Mobil Oil Co., Inc., Res. & Dev. Lab., Paulsboro, N. J. by E. B. Backensto, R. E. Drew, R. W. Manuel and J. W. Sjöberg.** Pub. 56-8. Per Copy \$2.50.

**T-5B-2 Effect of Hot Hydrogen Sulfide Environments on Various Metals—A Contribution to the Work of NACE Task Group T-5B-2 on Sulfide Corrosion at High Temperatures and Pressures in the Petroleum Industry: From Sinclair Res. Lab. Inc. Harvey, Ill.** Pub. 57-2. Per Copy \$3.00.

**T-5B-2 High Temperature Sulfide Corrosion in Catalytic Reforming of Light Naphthas—A Contribution to the Work of NACE Task Group T-5B-2 on Sulfide Corrosion at High Temperatures and Pressures in the Petroleum Industry: From Humble Oil & Ref. Co., Baytown, Texas.** Pub. 57-3. Per Copy \$1.50.

**T-8 Iso-Corrosion Rate Curves for High Temperature Hydrogen-Hydrogen Sulfide—A Contribution to the Work of NACE Tech. Group Committee T-8**, by E. B. Backensto and J. W. Sjöberg. Pub. 59-10. Per Copy \$1.50.

**T-8 Minimum Corrosion for Butane Isomerization Units. A Contribution to the Work of NACE Group Committee T-8 on Refining Industry Corrosion** by J. F. Mason, Jr. and C. M. Schillmoller. Pub. 59-11. Per Copy \$1.50.

**T-8 Corrosion of Refinery Equipment by Aqueous Hydrogen Sulfide. A Contribution to the Work of Group Committee T-8 on Refining Industry Corrosion** by Roy V. Comeaux. Pub. 59-12. Per Copy \$1.50.

**T-8A Precautionary Procedures in Chemical Cleaning. A Contribution to the Work of NACE Tech. Unit Committee T-8A on Chemical Cleaning**, by Robert A. Stander. Pub. 59-1. Per Copy \$1.50.

**T-8A Chloride Stress Corrosion Cracking of the Austenitic Stainless Steels—A Contribution to the Work of NACE Task Group T-8A on Chemical Cleaning**, by J. P. Engle, C. L. Floyd and R. B. Rosene. Pub. 59-5. Per Copy \$1.50.

Remittances must accompany all orders for literature the aggregate cost of which is less than \$5. Orders of value greater than \$5 will be invoiced if requested. Send orders to National Association of Corrosion Engineers, 1061 M & M Bldg., Houston, Texas. Add 5% per package to the prices given above for Book Post Registry to all addresses outside the United States, Canada and Mexico.

**NATIONAL ASSOCIATION  
OF CORROSION ENGINEERS**  
1061 M & M Bldg. Houston 2, Texas

## Pump and Valve Parts

(Continued From Page 24)

### Summary

Titanium is a suitable material for use in gas lift valves. Although Monel and stainless steels now occupy strong positions as materials from which most operating parts of gas lift valves are made, titanium should prove competitive at a somewhat lower price. Titanium exhibits excellent corrosion resistance when exposed to oil field salt water. Hydrogen sulfide brines do not notably affect it.

**TABLE 7—Erosion of Titanium and J-55 Steel vs Various Fluids and Flow Rates (Air Excluded)**

Exposure Time Hours	Specimen	VELOCITY			
		10 fps		40 fps	
		Wt. Loss gm	Corrosion Rate mpy	Wt. Loss gm	Corrosion Rate mpy
West Texas Crude Oil					
48.....	titanium			0.0477	6.7
	titanium	0.0041	0.57		
43½.....	polished titanium			0.0078	1.27
	polished titanium	0.0014	0.28		
20% West Texas Crude Oil; 80% 30,000 ppm NaCl brine					
31½.....	polished titanium			0.0012	0.26
	polished titanium	0.0	0		
42½.....	J-55 Steel			0.8038	53
	J-55 Steel	0.4694	34		
20% West Texas Crude Oil; 80% 30,000 ppm NaCl brine plus 1.2% 150-200 mesh screen sand					
42.....	polished titanium			0.1657	23.2
	polished titanium	0.0152	2.13		

**TABLE 8—Field Tests of Titanium, 9% Nickel Steel J-55 and N-80 Steels**

Duration of test.....23 days (July 16 to August 8, 1957).  
Crude Oil produced.....308 bbls.  
Brine produced.....4400 bbls.  
Formation gas.....285 MCF.  
Injection gas by gas lift.....138 MCF.

Coupon Number	Type of Coupon	Scale <sup>1</sup> mg	Corrosion Rate mpy	Coupled <sup>1</sup>	Appearance of Coupon
T-1	Titanium	1	.010	to J-55 <sup>1</sup>	Smooth
T-2	.....	2	.001	no	
T-3	.....	2	.001	to J-55 <sup>2</sup>	
T-4	.....	9	0.0	no	
9N-15	9% nickel steel	21	13	no	Striations & corrosion around hole <sup>3</sup>
9N-15	.....	33	2.5	no	
J-759	J-55	193	36.8	to Ti <sup>2</sup>	Mottled, uniformly corroded over 90%
J-782	.....	491	55.0	to Ti <sup>2</sup>	
J-761	.....	928	44.0	no	
J-787	.....	285	27.1	no	Mottled, uniformly corroded over 95% of area.
N-13	N-80	27	35.8	no	Mottled, severely but fairly uniformly corroded over 90% of area.
N-14	.....	29	36.8	no	

<sup>1</sup> Coupons were arranged as shown in Figure 5. Short Coupled coupons are coupled through a washer. Long Coupled<sup>2</sup> coupons are at the upper and lower ends of the holder.

<sup>2</sup> Long coupled coupons are coupled through a washer, a bolt, the frame and another washer.

<sup>3</sup> Deeply corroded around bolt hole, numbered face of 9N-15.

<sup>4</sup> Scale quantities shown were on coupon when received. The scale was acid-soluble and is believed to be preponderantly calcium carbonate.



Titanium was found to be cathodic to the grades of steel usually employed for oil well tubing. Results of field tests of metal coupons in oil well fluids, however, were not deemed conclusive as to the extent of increased galvanic corrosion that could be attributed to the difference in potential.

Titanium showed good resistance to erosion by sand-laden oil well fluids. Extremely good performance was obtained under conditions simulating the flow in oil well tubing both with natural flow and artificial lift.

Titanium ball and seat type valves, such as are commonly found in submerged oil well pumps were field tested for a year. Titanium parts did not equal durability of competitive types. Hard-

ened seat faces and balls may make titanium satisfactory for use in pumping wells. Although titanium is hardenable by cold working only, titanium alloys may be hardened by any process.

Titanium balls and seats cost \$20.22 per set, whereas the cost of comparable conventional types varies from \$9.31 to \$16.78 per set. Thus, titanium is at a disadvantage. Production cost for titanium units undoubtedly could be reduced to make prices nearer the same.

Further evaluation of titanium for the two applications is justified by the results reported. Limitations of laboratory testing necessitate additional study but enough have been obtained to warrant further investigation.

(Continued on Page 30)

**TABLE 9—Field Test of Titanium, 9% Nickel Steel, J-55 and N-80 Steels**

Duration of test.....	22 days, August 8 to August 30, 1957
Crude oil produced.....	398 bbls.
Brine produced.....	6084 bbls.
Formation gas.....	369 MCF.
Injected gas by gas-lift.....	1783 MCF.

Coupon Number	Type of Coupon	Scale <sup>3</sup> mg	Corrosion Rate mpy	Coupled <sup>1</sup>	Appearance of Coupon
T-5	Titanium		.002	to N-80 <sup>1</sup>	Smooth
T-6			.004	no	
T-7			.006	to N-80 <sup>2</sup>	
T-8			.012	no	
9N-9	9% Nickel		.37	no	Striations & corrosion around bolt hole.
9N-12			.40	no	
J-769	J-55		44.7	no	Mottled. Uniformly corroded over 95% of area.
J-795			35.5	no	
N-18	N-80		236.2	to Ti <sup>1</sup>	Mottled & striated. Severely but fairly uniformly corroded over all
N-19			79.0	no	
N-22	N-80		124.5	no	Mottled & striated. Uniformly corroded over 95% of area.
N-23			65.6	to Ti <sup>2</sup>	

<sup>1</sup> Coupons were arranged as shown in Figure 5. Short coupled coupons are coupled through a washer. Long coupled coupons are at upper and lower end of the holder.

<sup>2</sup> Long coupled coupons are coupled through a washer, a bolt, the frame and another washer.

<sup>3</sup> No scale weights were made on these coupons.

**TABLE 10—Electrochemical Potentials of Titanium and Oil Well Steels**

Potential (Volts) in brine from a well in Magnet Withers Field, Wharton, County, Texas, using standard saturated calomel electrode.

Metal	Time (Minutes)						
	0	2	4	6	8	10	12
J-55.....	0.4938	0.5811	0.6104	0.6191	0.6245	0.6281	0.6318
N-80.....	0.4930	0.5620	0.5813	0.5992	0.6110	0.6192	0.6250
P-110.....	0.4500	0.5263	0.5715	0.5934	0.6065	0.6150	0.6212
Titanium.....	0.3471	0.3393	0.3391	0.3325	0.3287	0.3234	0.3174

#### PROCESS OF MANUFACTURE AND CHEMICAL REQUIREMENTS

Process of Manufacture and Material	Grade API Designation	Phosphorus, Max., %	Sulfur, Max., %
Casing and Tubing Seamless or Electric-Welded Electric-furnace, open-hearth, basic oxygen or killed deoxidized basic bessemer.....	J-55, N-80	0.04	0.06
Electric-furnace, open-hearth or basic-oxygen.....	P-110	0.04	0.06
Killed deoxidized acid bessemer or killed deoxidized basic bessemer.....	J-55, N-80	0.110	0.065

#### TENSILE REQUIREMENTS:

Grade	Yield Strength Min., psi	Tensile Strength Ult., psi
J-55.....	55,000	75,000
N-80.....	80,000	100,000
P-110.....	110,000	125,000



## TECHNICAL REPORTS

on

### CORROSION PROBLEMS in the PROCESS INDUSTRIES

On sales to Texas addresses, add 2% tax.

**TP-5A** Materials of Construction for Handling Sulfuric Acid. Corrosion, August, 1951, issue. Per Copy \$1.50.

**T-5A** Qualified Approval for D-319 Analysis Austenitic Chromium-Nickel-Molybdenum Stainless Steel. A Report of NACE Technical Unit Committee T-5A On Corrosion in Chemical Processes. Publication 60-10. Per Copy \$1.50.

**T-5A-3** Corrosion by Acetic Acid—A Report of NACE Task Group T-5A-3 On Corrosion by Acetic Acid. Pub. 57-25. Per Copy \$2.50.

**T-5A-4** A Bibliography on Corrosion by Chlorine. A Report of Technical Unit Committee T-5A on Corrosion in the Chemical Manufacturing Industry. (Compiled by Task Group T-5A-4 on Chlorine.) Pub. 56-2. Per Copy \$2.00.

**T-5A-4** Summary of Replies to Questionnaire on Handling of Chlorine Mixtures—A Report of NACE Task Group T-5A-4 on Chlorine. Pub. 59-15. Per Copy \$1.50.

**T-5A-5** Corrosion by Nitric Acid. A Progress Report by NACE Task Group T-5A-5 on Nitric Acid. Per Copy \$1.50.

**T-5A-5** Aluminum vs Fuming Nitric Acids. A Report by NACE Task Group T-5A-5 on Corrosion by Nitric Acids. Per Copy \$1.50.

**T-5A-6** Summary of Replies on Corrosion in HF Alkylation Units—A Report of NACE Task Group T-5A-6 on HF Corrosion. Pub. 59-14. Per Copy \$1.50.

**T-5B** High Temperature Corrosion Data. A Compilation by NACE Technical Unit Committee T-5B on High Temperature Corrosion. Pub. 55-6. Per Copy \$1.50.

**T-5B-3** The Present Status of the Oil Ash Corrosion Problem. A Progress Report of NACE Task Group T-5B-3 on Oil Ash Corrosion. Pub. 58-11. Per Copy \$1.50.

**T-5B-3** The Residual Oil Ash Corrosion Problem, by C. J. Slunder and Bibliography for Residual Fuel Oil Ash Corrosion. A Report of NACE Technical Unit Committee T-5B, High Temperature Corrosion, prepared by Task Group T-5B-3 on Oil Ash Corrosion. Publication 60-6. NACE Members \$2.00; Non-members \$2.50 Per Copy.

**T-5C-1** Some Economic Data on Chemical Treatment of Gulf Coast Cooling Waters. A Report of the Recirculating Cooling Water Sub-Committee of NACE Task Group T-5C-1 on Corrosion by Cooling Waters, South Central Region. Per Copy \$1.50.

**T-5C-1** Water Utilization and Treatment Efficiency of Gulf Coast Cooling Towers—A Report of the Recirculating Cooling Water Work Group of NACE Task Group T-5C-1 on Corrosion by Cooling Water (South Central Region). Pub. 57-20. Per Copy \$1.50.

**T-5C-1** Evaluation of Laboratory Testing Techniques for Cooling Water Corrosion Inhibitors. A Report of Task Group T-5C-1 on Corrosion by Cooling Waters (South Central Region). Pub. 57-12. Per Copy \$1.50.

**TP-5C** Stress Corrosion Cracking in Alkaline Solutions. Pub. 51-3. Per Copy \$2.00.

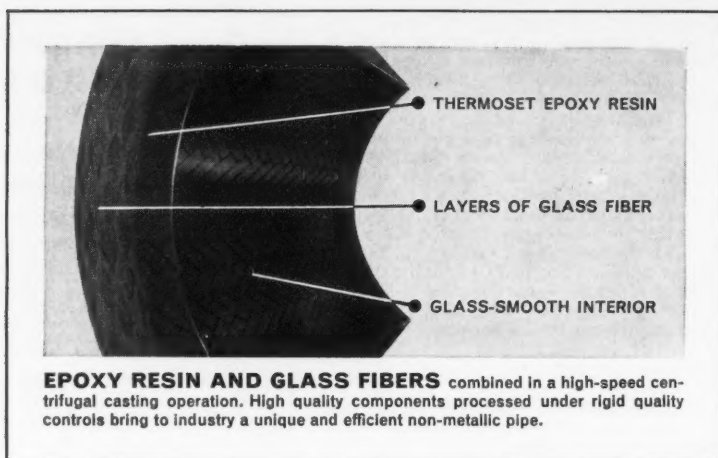
**T-5E** Report on Stress-Corrosion Cracking of Austenitic Chromium-Nickel Stainless Steels. Sponsored jointly by ASTM Committee A-10 on Iron-Chromium, Iron-Chromium-Nickel and Related Alloys, and NACE Technical Unit Committee T-5E on Stress-Corrosion Cracking of Austenitic Stainless Steels. ASTM Special Technical Publication No. 264. Members \$4.80; Non-members \$6 Per Copy.

Remittances must accompany all orders for literature the aggregate cost of which is less than \$5. Orders of value greater than \$5 will be invoiced if requested. Send orders to National Association of Corrosion Engineers, 1061 M & M Bldg., Houston, Texas. Add 7% per package to the prices given above for Book Post Registry to all addresses outside the United States, Canada and Mexico.

## NATIONAL ASSOCIATION OF CORROSION ENGINEERS

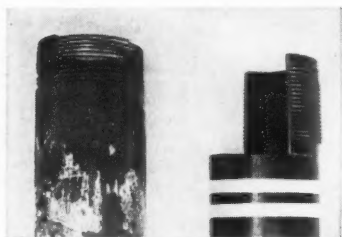
1061 M & M Bldg. Houston 2, Texas





## "Impossible" corrosion, temperature and pressure problems solved by Fibercast<sup>®</sup> epoxy pipe

- Operating temperature range wider than any non-metallic pipe (−65° to 300° F.)
- Operating pressure range extends to 1000 psi.
- Effectively combats corrosion, contamination, abrasion, scaling, electrolytic action.



Fibercast Tubing (right) used to suspend a 1,200 lb. pump for 3 years in a salt water supply well. There was no loss in strength. The damaged plastic-coated steel nipple (left) was used in the same installation, failed after 3 months' service.

### WHAT is Fibercast?

It is a centrifugally cast, thermoset, epoxy resin reinforced pipe that handles temperature and pressure problems where no other non-metallic pipe will do.

Its body of woven glass fibers provides resistance to high tension forces. These fibers, combined by adhesion, are imbedded and bonded by heat in epoxy resin. The result is a strong, long-lasting pipe with remarkable ability to withstand high pressure and

temperature in corrosive environments.

### WHY use Fibercast?

For a multitude of reasons. Because its advantages range from superior resistance to heat, pressure and corrosion, to its ease of handling, light weight, dielectric properties and structural stability. Because Fibercast's long service life alone would justify choosing it over other materials. Because even more expensive metal pipe or pipe with thermo-plastic interior coatings cannot match Fibercast's proven durability. Case histories and accurate testing have proved over and over that Fibercast performs better, lasts longer, costs less. Out of 338 common corrosive solutions, Fibercast competently handles 320. And naturally, Fibercast's unique and lasting qualities under such conditions mean that it drastically reduces maintenance and replacement costs, too.

Although Fibercast's light weight makes it correspondingly easy to work with (it is less than 25% the weight of steel), it has the same basic linear coefficient of expansion as steel (7.06

### COMPARATIVE LIFE DATA\*

FIBERCAST, GRADE J	1.00
ALUMINUM	.26
BRASS (RED)	.74
RUBBER HOSE	.210
STEEL (Stainless 304-40)	.311
ASBESTOS (Cement-C-100)	.237

\*Basing Fibercast as unit life of 1 and others as comparative percentages thereof.

x  $10^{-6}$  to  $8.25 \times 10^{-6}$  in./in./°F.). Fibercast's strength permits installation on pipe racks with span lengths generally used for metal pipe.

The pipe has a smooth interior, with a Hazen-Williams C Flow Factor of 147. This cuts friction losses, aids flow and tends to resist build-up. It is a non-conductor (accepted by the electrical industry as a superior insulator), and is not subject to cold flow. A low coefficient of heat transfer ( $3.0 \times 10^{-3}$  Cal/CM<sup>2</sup>/sec/CM°C.),



minimizes heat loss and may even eliminate heat tracing.

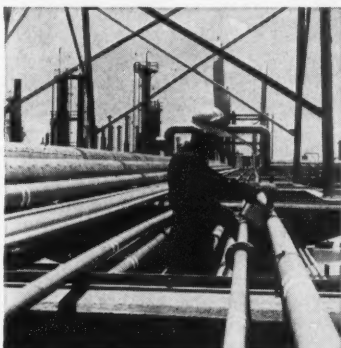
All three major systems of joining all pipe are used with equal success on Fibercast. They are: standard flanged, cemented, and threaded and coupled with a complete selection of Fibercast fittings (the world's largest line of corrosion-resistant epoxy pipe fittings).

Safety, too, is an important reason for using Fibercast Pipe in transporting dangerous chemicals, particularly in areas where the pipe is adjacent to personnel. Most piping materials corrode undetectably from inside-to-out and can suddenly burst without warning, inflicting injury to personnel. Because of Fibercast's woven glass fiber construction, such occurrences, if they ever occur, are detectable in minute, repairable leaks.

#### WHO uses Fibercast?

The petroleum industry . . . chemical . . . petro-chemical . . . nuclear energy . . . textile . . . paper . . . and food-processing industries . . . countless operations handling acids, alkalis, salt water and other corrosive liquids under pressure can all use Fibercast profitably.

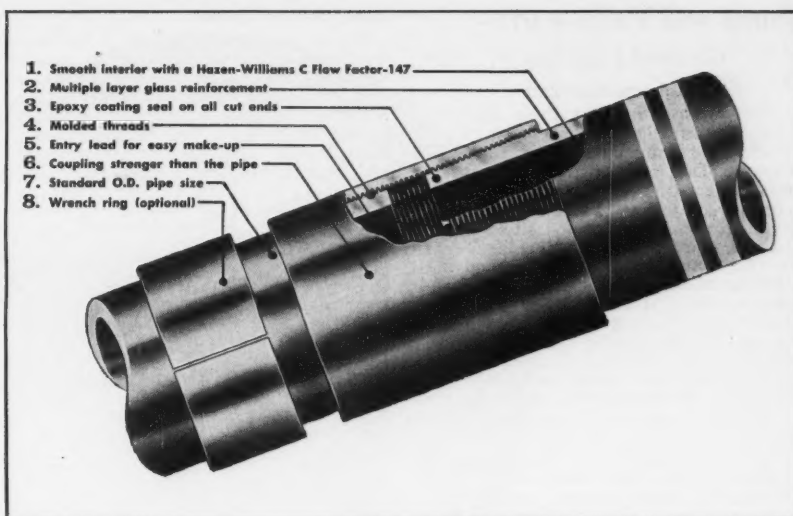
In oil country, Fibercast is already



Workman is painting a section of Fibercast Pipe bearing 32% HCl at Shell's Texas Chemical plant. Note that Fibercast has sufficient strength for installation on span racks with the spacing normally used for metal pipes.

widely acclaimed for superior performance in rugged, abusive and even high pressure installations like salt water disposal wells and horizontal lines. In cases where other pipe and tubing required replacement after just a few weeks of service, Fibercast is still performing efficiently after many years.

In petro-chemical and chemical-processing plants, Fibercast is valued



#### 8 Points of Fibercast Superiority

not only for high heat and corrosion resistance, but also for its remarkable maintenance of the purity of the solutions it is required to carry. Such installations range from Fibercast pipes which carry 37% hydrochloric acid at ambient temperatures to lines carrying solutions containing brine, alum, and other sulphates, sulphuric and phosphoric acids, and other damaging chemicals.

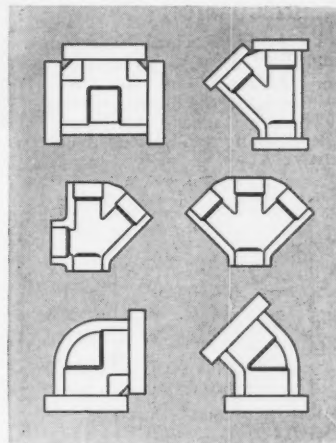
Food-processing industries, among the most demanding of all industries in purity, corrosion and heat standards of operation, know the long-term benefits of using Fibercast. Fibercast is especially effective in the processing of foods requiring use of sulphuric and phosphoric acids (such as corn syrup, starches, gelatins), as well as brines and other highly corrosive acids and solutions.

The operating conditions peculiar to the man-made textile and paper processing plants are also improved by the use of Fibercast Pipe and Fittings. The ever-growing demands of all industry . . . the rigid quality controls imposed by governmental and other agencies . . . the unique and often unsolved needs of new processes and methods . . . all of these factors help to create "impossible" problems that can be solved by the use of Fibercast.

#### Complete Line of Fittings

Fibercast provides fittings to solve any fitting problem. Besides a vast stock of standard sizes and types, Fibercast also designs and makes spe-

cial fittings to meet individual requirements. All, of course, have the same corrosion, pressure and heat resistance properties of Fibercast Pipe and Tubing. A few of the regularly stocked types are shown in the line drawings below



If you have an "impossible" corrosion, temperature or pressure problem, consider Fibercast. This remarkable pipe can save you money as it has so many other industries. Get the full story without obligation now. Simply mail this coupon.

**FIBERCAST COMPANY C-111**  
**BOX 727, Sand Springs, Oklahoma**  
 Please send me further information  
 about Fibercast Tube and Pipe.

Name \_\_\_\_\_  
 Title \_\_\_\_\_  
 Firm \_\_\_\_\_  
 Type of Business \_\_\_\_\_  
 Address \_\_\_\_\_  
 City \_\_\_\_\_ State \_\_\_\_\_

**FIBERCAST**  
 COMPANY

A DIVISION OF  
**Youngstown**  
 SHEET AND TUBE COMPANY



## Pump and Valve Parts—

(Continued From Page 27)

### Acknowledgments

The authors express their appreciation to the Pigments Division, E. I. DuPont de Nemours and Co., Inc., Wilmington, Del., for the grant under which this project was carried out, to the various oil companies which cooperated in making the field tests possible and to Camco, Incorporated, Houston, Texas, for valuable help in supplying and machining titanium. Titanium for ball and seat combinations was supplied by Rem-Cru Titanium, Inc., Midland, Pa., (now Crucible Steel); balls were fabricated by Industrial Techtonics, Ann Arbor, Michigan; seats were made by Bradford Motor Works, Bradford, Pa.

Monel (copper-nickel alloy) is a trade name of International Nickel Co., Inc., New York City, N. Y. Hastelloy A (nickel-molybdenum-iron alloy) and Haystellite (cast tungsten carbide) are trade names of Union Carbide Corp., New York City, N. Y. Ni-Chrome (chromium alloy steel) is marketed by Bradford Motor Works, Bradford, Pa.

### References

1. *Ind and Eng Chem*, 50, No. 9, Part 2, 1493-95.
2. Corrosion of Oil and Gas Well Equipment.
3. NACE-API (1958), Division of Production, API, Dallas, Texas, p. 26.
4. *Ibid.*, p. 7.

### DISCUSSION

**Question by A. H. Roebuck, Western Company, Fort Worth, Texas:**

In cost per length of life service, is titanium now competitive? If so, where? Does it have some specific application where under specific applications it can be competitive?

**Reply by F. W. Jessen:**

Insofar as the application of titanium to gas lift valves and subsurface pumping equipment is concerned, it appears titanium is definitely competitive as a material for gas lift valves. Since so little information is available, however, on sustained length of service as ball and seat combinations in subsurface pumps, no specific information can be given at present as to the competitive

position of titanium. Undoubtedly where severe conditions of corrosion are encountered, titanium should prove competitive.

Titanium will not likely be found to be competitive in shielding of splash zones in many off-shore installations. To date, however, little concrete data is available on such applications and no conclusive evidence exists as to this specific application.

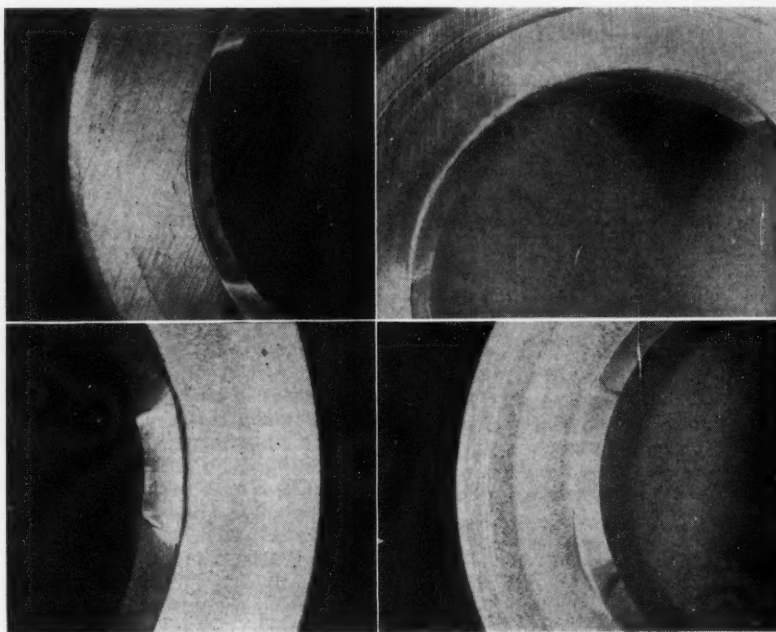


Figure 8—Close-up views of titanium seats showing erosion by well fluids.

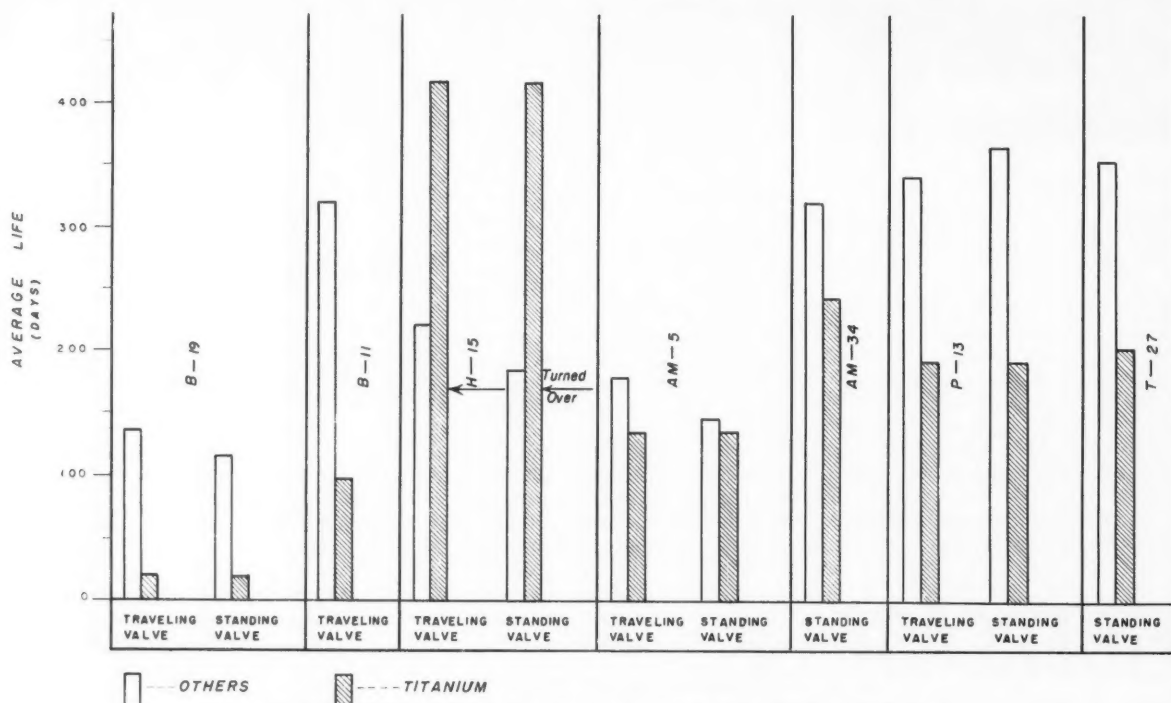


Figure 9—Titanium ball and seat field test, Caldwell and Guadalupe Counties, Texas.



# FIBERGLASS REINFORCED ATLAC<sup>®</sup> 382

corrosion resistant  
construction material  
for process  
equipment

Where corrosive fluids take too great a toll—in tanks, ducts, fume hoods and similar equipment—you and your fabricator should take a long look at glass reinforced ATLAC 382. It offers you seven distinct advantages for process equipment:

**1 Corrosion resistance** ATLAC 382 is vastly superior to ferrous metals in corrosion resistance, and generally superior to most non-ferrous metals and alloys, as well as general purpose polyester and epoxy resins. It resists attack by many aqueous solutions of acids, salts, bleaches and alkalis, at temperatures up to 250° F. Typical service histories: a tank of ATLAC 382 still in mint condition after 2 years' alternately storing 14% sodium hypochlorite and caustic soda...no attack whatsoever on an ATLAC 382 elbow and damper used to exhaust sulfuric acid pickling fumes...zero down-time for a nitric acid scrubber of ATLAC 382, even after 6 years of constant use.

**2 High strength** Pound for pound, reinforced ATLAC 382 is stronger than steel. You get the same total strength with less total weight. Examples: 30,000-gallon tanks of ATLAC 382 are completely self-supporting...and even the largest hoods need no corrosion-prone metal bracing.

**3 Light weight** Equipment of ATLAC 382 is generally lighter than wood, Transite, or metal equipment. In one case, a 1,000-gallon tank of ¾" ATLAC 382 weighed 300 pounds, compared with

4.3 times that weight for alloy steel.

**4 Economy** ATLAC 382 equipment generally costs one-half to one-third less than rubber-lined or tiled equipment, and is normally equal to 304 and lower in price than 316 stainless steel. It is almost always a better buy than the more exotic metals if temperatures and pressures are not too high.

**5 Design flexibility** There are very few practical limits in size and shape for equipment of ATLAC 382. What's more, equipment can sometimes be redesigned to take advantage of ATLAC 382's unique structural characteristics—resulting in extra simplification, practicality and cost reduction.

**6 Easy installation** Because of reinforced ATLAC 382's light weight, relatively few men are needed to install it. Also, since it can be joined right on the job site, large equipment can be shipped in sec-

tions and field-erected. Equipment is readily changed and modified. Ducting can be relocated and re-assembled without special equipment or personnel.

**7 Low maintenance** ATLAC 382 equipment needs virtually no periodic maintenance. It never needs painting or rust removal, always looks clean and attractive. Physical damage is easy to repair generally without down-time.

But why not get the feel of ATLAC 382 for yourself? Let us send you details on ATLAC 382, its uses and a comparison of the corrosion resistance of various reinforced plastics. At the same time, we'll be glad to supply a test sample so you can prove to your own satisfaction that ATLAC 382 is well worth considering. For your sample—and data on ATLAC 382—mail the coupon, or write Atlas direct.

Atlas Chemical Industries, Inc.  
Wilmington 99, Delaware

Please send details on ATLAC 382, and a free test sample.

NAME ..... TITLE .....

COMPANY .....

ADDRESS .....

CITY ..... ZONE ..... STATE .....

**ATLAS** CHEMICAL INDUSTRIES, INC.



# Chlorinated Polyether

## Abstract

Describes laboratory and field test data to show probable use of chlorinated polyether coatings produced by water suspension system. Outlines steps in proper application of the coating system. States that coating can be used on mild steel, stainless, Hastelloys, copper, brass and bronze. Tabular data show partial list of materials to which chlorinated polyether is resistant to 220 F and give results of laboratory corrosion tests on this polyether coating applied to mild steel. 5.4.5

## Introduction

**L**ABORATORY AND FIELD corrosion tests have shown that a chlorinated polyether coating produced from a water suspension system is an effective barrier to corrosion under many severe service conditions. Permeability, inherent with this material as with other plastic coatings, has been minimized to the extent that a field failure has not been observed to date which could be attributed directly to permeability.

The coating system described in this article was made of Penton,\* a high molecular weight plastic which has outstanding chemical resistance at elevated temperatures. Table 1 gives a partial list of the materials to which this chlorinated polyether is resistant to 220 F. This material's other characteristics also indicated its desirability as basis for a coating for chemical equipment. Its low melt viscosity and good resistance to thermal degradation at melt temperatures suggested that dense, impervious coatings could be formed with heat.

A research program devoted to producing a suitable coating was begun by Pfaudler Research Laboratory in 1958. Efforts were directed to development of a sprayable system which would make possible the coating of large, complex processing equipment. Conventional solvent systems were considered unlikely because of the limited solubility of chlorinated polyether. The only known solvent for this material is cyclohexanone which dissolved a maximum of 10 to 15 percent solids even when hot. Research, therefore, was concentrated on formulation of a water based suspension. An extra benefit of a water system is the elimination of any toxicity or flammability hazard inherent with some solvent systems.

Other objectives of the research program were that the suspension should be stable, that thick films could be applied in one application and that physical

**TABLE 1—Partial List of Materials to Which Chlorinated Polyether is Resistant to 220 F**

Inorganic	Organic
Acetic Acid	Alcohol-Amyl, Butyl, Ethyl, etc.
Aluminum Hydroxide, Fluoride, Chloride, etc.	Benzoic Acid
Ammonium Hydroxide, Fluoride, Chloride, etc.	Butadiene
Brine	Butane
Calcium Chloride, Hydroxide, Oxide, etc.	Carbon Tetrachloride
Caustic Soda	Crude Oil
Chromic Acid	Ethyl Chloride
Hydrobromic Acid	Formaldehyde
Hydrochloric Acid	Fruit Juices
Hydrofluoric Acid (60%)	Glycerin
Nitric Acid (10%)	Heptane
Phosphoric Acid	Hexane
Plating Solutions—Brass, Copper, Chrome, etc.	Kerosene
Potassium Hydroxide, Chloride, etc.	Propane
Sodium Hydroxide, Chloride, etc.	Tanning Liquors
Water	Turpentine
Zinc Chloride, Nitrate, etc.	Urea

\*Trademark for chlorinated polyether manufactured by Hercules Powder Co., Wilmington, Del.



# Coatings Produced by Water Suspension System\*

O. J. Britton  
W. A. Carlson  
J. R. Little

*Pfautler Company  
Rochester, New York*

and chemical properties of the pure resin should be retained.

While research was underway on the water suspension formulation, additional work was begun to evaluate the properties of chlorinated polyether when applied as a coating. Conventional dry techniques such as the fluidized bed were used to apply this polyether to samples for chemical and physical tests and to coat small items for field testing. The data on the pure resin provided basis for eventual comparison with the water based coating system.

By 1959, a water suspension formulation had been developed and was used for early pilot orders and field tests. Original objectives had been satisfied: coatings in excess of 10 mils could be applied in one application with conventional spray equipment; stability was excellent; preliminary tests showed that the system offered the same degree of protection as pure chlorinated polyether resin.

## Coating Procedure

Because the polyether was being applied from a new type of suspension system, many problems in application were encountered. Details of each step of the coating process first evolved from the laboratory and were modified later by production experience.

First essential step in the coating procedure is a thoroughly clean surface that has been roughened by sandblasting. Ordinary spray equipment is used to apply films of 10 mils or thicker. The wet coat is dried at room temperature or at high temperatures to 200 F. When the water has been removed, the coated piece is heated and the coating sintered at 400 to 500 F in an oven. Additional applications are made in this same manner until the desired thickness is obtained.

After the final coat has been fused, the hot piece is taken directly from the oven and quenched in

cold water. Although this step is not necessary in all cases, certain benefits are derived from a quick quench. Chlorinated polyether is normally a crystalline material. A slow-cooled coating is highly crystallized and quite rigid by the time it reaches room temperature. Furthermore, because the thermal expansion of chlorinated polyether is considerably higher than the base metal, a slow-cooled coating contains stresses which tend to weaken its mechanical bond with the base metal. A quenched coating, on the other hand, is retained temporarily in an amorphous condition since it passes quickly through the temperature region where crystal formation most readily occurs. Immediately after quenching, chlorinated polyether in its amorphous state is soft and flexible enough to stress relieve itself while maintaining good adhesion and high gloss. Within a few hours, crystallization at room temperature progresses to a point where the coating is hard and durable.

## Tests Made on Coating Quality

Water based coatings can be applied that are pin-hole free as determined by a 5000-volt a-c electric test, normally used for quality control in production. A 3500-volt test is recommended for checking continuity of coated items after delivery or after service in the field. A constant voltage tester developed for use with glass coatings has proved satisfactory for this use.

Tensile tests show the adherence of chlorinated polyether applied to a sandblasted surface to be in the 4500 psi range on mild steel and 200 psi on aluminum. On tensile tests of the type used to determine these figures, surface preparation of the sample and tests methods are so important that the results

(Continued on Page 35)

\*Revision of a paper titled "Penton Coatings for Industrial Uses" presented at the Northeast Region Conference, National Association of Corrosion Engineers, October 11-14, 1960, Huntington, W. Va.





## GRAPHITE ANODES ARE BEST!

### FOR LOW COST...

"National" graphite anodes provide ample conductivity for economical ground bed design in both low and high resistance soils. Installed with graphite particle or coke backfill, "National" anodes offer low initial cost; exceptionally long life.

National Carbon manufactures a complete line of anodes providing the economies of graphite to all types of cathodic installations.

3" x 60" and 4" x 80"  
sizes in plain and NA Graphite

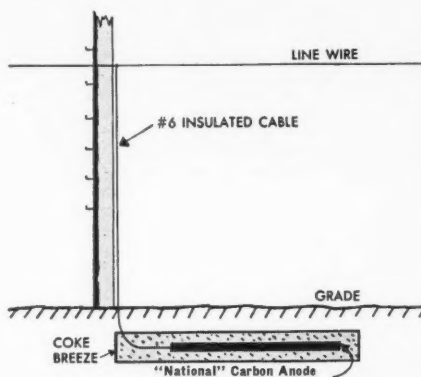
3" x 30" and 3" x 60"  
NA Graphite Anodes with Type QA Connections

2" x 12", 2" x 20" and 3" x 30"  
Type QA Anodes of NA Graphite

If you do not use "National" Graphite Anodes for cathodic protection, try them! We believe you'll find

**"NATIONAL" GRAPHITE ANODES ARE BEST  
FOR LONG LIFE AND LOW COST!**

### FOR LONG LIFE...



Since 1943, a distributed "National" carbon anode system has protected 2042 feet of 4 inch bare steel main for a large Eastern utility company. Installed horizontally (see diagram) to avoid shale rock, 16 — 2" x 80" anodes are spaced approximately 120 feet apart to obtain uniform protection.

Before installation of the "National" carbon anodes, 4 leaks occurred on the main in one year. Since cathodic protection began in October, 1943, there has not been a single leak.

#### INSTALLATION DATA

Anode size: "National" 2" x 80" Carbon

Backfill: Coke breeze

Length of anode service: 15-30 ampere-years  
per anode

Average soil resistance: 1000 to 10,000  
Ohm. cm.

"National" and "Union Carbide" are registered trade-marks for products of

## NATIONAL CARBON COMPANY

Division of Union Carbide Corporation • 270 Park Avenue, New York 17, New York  
IN CANADA: Union Carbide Canada Limited, Toronto

**UNION  
CARBIDE**



(Continued From Page 33)

are most meaningful if compared with similarly prepared specimens of other materials. Therefore, other coating systems were evaluated by the same techniques. The adherence of chlorinated polyether to mild steel compared favorably with adherence values for vinyl-steel and phenolic-steel systems. Good adhesion also has been confirmed by field installations.

Efforts are being made to improve adherence to aluminum. Through use of prime coats, bond strengths to aluminum have been improved as much as 60 percent in the laboratory.

#### Coatings on Other Metals

Most experimental work was on use of mild steel and cast iron as the base metal for the chlorinated polyether coating system. This water suspension coating also can be satisfactorily applied to stainless steel, the Hastelloys, brass, bronze and copper. Quality coatings with good adherence on each of these metals require a clean, rough, non-porous surface. As with any coating system, blow holes and cavities in the base metal which must be bridged to form a continuous film are sources of trouble, either during coating application or after a period of service.

#### Performance Data From Field Tests

Ultimate use of these coatings, regardless of how easily they can be applied, depends on the corrosion resistance of the coatings both to chemical attack and to permeation. To date, there are insufficient data on the effects of permeation to establish satisfactory service recommendations for coatings. Information from laboratory and field tests do give some perspective as to areas in which this material probably can be used. Table 2 summarizes the laboratory corrosion tests which have been run sufficiently long to permit valid observations.

In these tests, coated mild steel plates were tested in both liquid and vapor phase. Results in both phases always were similar although more pronounced in the liquid phase. Base metal discoloration is attributed to permeation of minute quantities of reagents through the coating to the base metal.

**TABLE 2—Laboratory Corrosion Tests on Chlorinated Polyether Coatings on Mild Steel**

Satisfactory Performance			Observations
Corrosive	Time (Days)	Temp. (F)	
H <sub>2</sub> O	49	210	Slight base metal discoloration
30% H <sub>2</sub> SO <sub>4</sub>	90	210	
20% HCl	260	210	Coating discolored. Slight base metal discoloration
37% HCl	30	210	
10% H <sub>3</sub> PO <sub>4</sub>	30	210	Slight base metal discoloration
28% NH <sub>4</sub> OH	30	150	No effect
30% NaOH	90	210	Slight base metal discoloration
Beer	90	125	No effect
30% KCl	30	160	
Borderline Performance			
10% HNO <sub>3</sub>	90	210	
80% HAc	30	210	Coating bleached. Corrosion residue on surface Strong base metal discoloration. Bond extremely weak
Unsatisfactory Performance			
28% NH <sub>4</sub> OH	90	210	
			Coating discolored and blistered

Additional information is available from field tests. Over 400 coated test samples and prototype pieces have been provided for field testing. They have consisted of standard test coupons and other items such as centrifuge baskets and parts, valves, paper rolls, agitators, pump impellers and casings, filter press plates and frames, thermowells, flow meter parts, duct work and process tanks to 200 gallons coated either on the outside or the inside.

Successful field tests have been reported as follows:

1. Dilute NaOCl in NaOH, 80 F, six weeks.
2. Benzene, CC14, concentrated HCl mixture, 80 F, 38 days.
3. Alternating 307 F steam and 150 F water every three minutes continuously for 16 days.
4. Hard chrome plating solution, 120 F, eight days.
5. HF, HCl and SO<sub>3</sub> mixture, 200 F, two weeks.
6. Solution of chlorine and 8½ percent caustic soda, 170 F, five months.
7. Outdoor exposure in mild industrial atmosphere, one year.
8. Chlorine dioxide (primary generator), 83 F, five weeks.
9. HNO<sub>3</sub>, HCl, H<sub>2</sub>SO<sub>4</sub> vapors in atmosphere, 100 F, seven months (exterior coating).
10. HF mixture at reflux, longer than two months (details confidential).
11. Laboratory sink traps exposed to a wide variety of organic and inorganic reagents, 1½ years.

Other field tests, however, indicated the coating was affected by the three following conditions: (1) 30 percent KCl brine in Hooker Cell, 200 F, two weeks, (2) liquid bromine, 75 F, two days and (3) one-to-one HCl, reflux, 100 hours.

#### Conclusions

From these laboratory and field corrosion tests, it is concluded that chlorinated polyether coatings produced from the water suspension system are an effective barrier to corrosion under many severe service conditions.

Extensive testing is being continued to establish additional data on service limitations to prevent misapplications.

This coating system probably can give satisfactory service in many applications where conditions are more severe than can be handled by PVC and in some cases where fluorocarbons are now used.

#### DISCUSSIONS

**Question by E. W. Verecke, Cleveland, Ohio:**

Please comment on the applied cost of Penton coatings in regard to square foot area.

**Reply by O. J. Britton:**

Penton coatings applied by the Pfaudlon sprayed dispersion process cost about \$4 to \$6 per square foot. This is a very rough approximation in that higher or lower costs may be experienced depending on the configuration and area of the objects to be coated.

**Question by Lowell R. Yates, Huntington, West Virginia:**

Can Penton coatings be applied to cast iron filter press plates?

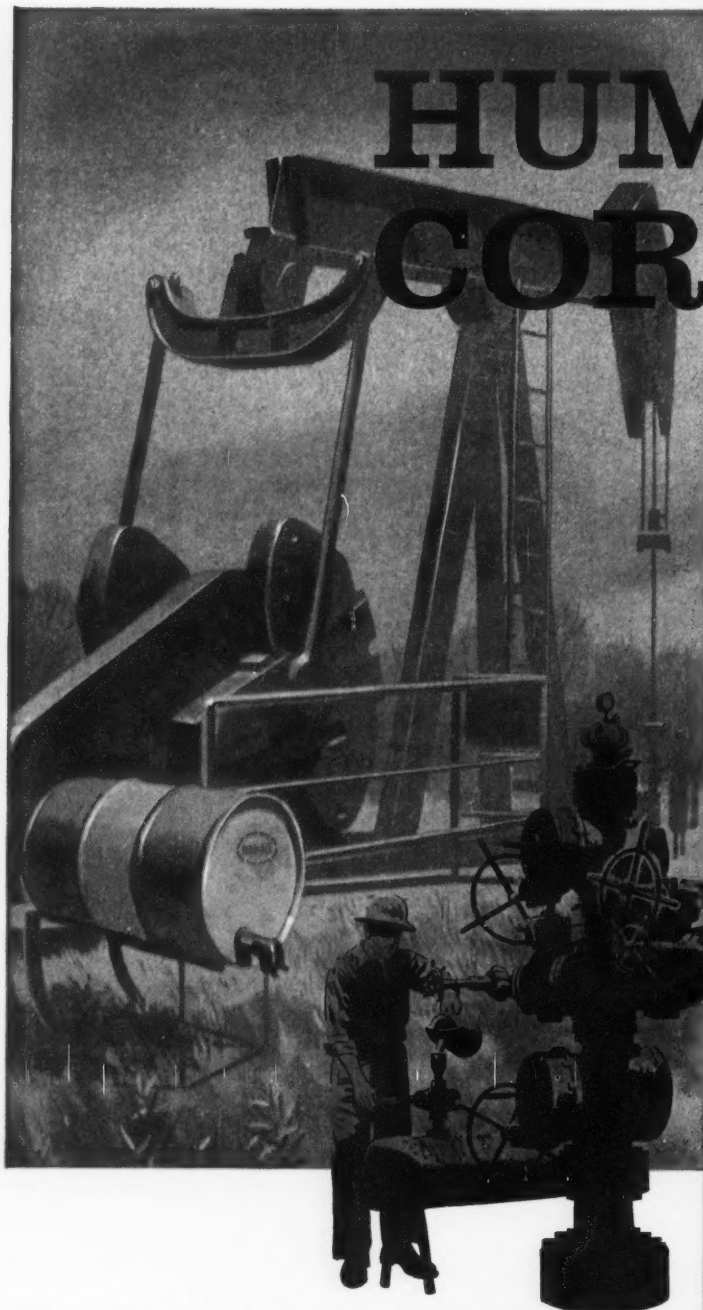
**Reply by O. J. Britton:**

Yes. Castings must be sound.



**Before Corexit:** As many as 16 rod jobs on 9 wells in 1 month

**After Corexit:** Only 4 rod jobs in any 1 year!\*



# HUMBLE COREXIT®

## CORROSION INHIBITORS

\* *COREXIT saved \$1,010 per well per year in one field . . . \$780 per well in another . . . has proved highly profitable in thousands of wells. In both sour and sweet crude fields, COREXIT corrosion inhibitors prolong life of sub-surface equipment, reduce well-pulling jobs and prevent production losses . . . usually through simple batch treatment.*

In deep high pressure, high bottom-hole temperature wells, *squeeze treatment* with COREXIT is opening new opportunities for economical corrosion control. Only a few treatments per year are usually required.

Find out how COREXIT can cut your costs. Call your Humble Salesman, or contact Humble Oil & Refining Company, Houston, Texas. COREXIT is available for immediate delivery from Humble Bulk Plants.

**HUMBLE OIL & REFINING CO.**  
*America's Leading ENergy Company*

©ENCO and COREXIT are registered trademarks of Humble Oil & Refining Company



**PRODUCTS**



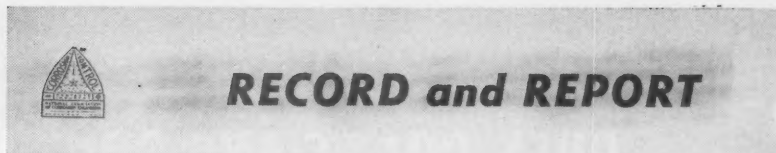
## Diffraction Reveals Surface Reactions of Metals to Gases

A new method of studying atomic surface reactions of metals to gases is expected to add considerably to understanding such surface phenomena as catalysis and corrosion.

By diffracting low energy electrons from a surface and accelerating them by a strong electric field to a fluorescent screen, a diffraction pattern is produced on the screen. This pattern reveals the arrangement of the first monolayer of atoms on the surface.

The low energy electron diffraction technique and findings were described by the developer, L. H. Germer, and A. U. MacRae, both of Bell Telephone Laboratories, 463 West Street, New York 14, N. Y., at the International Conference on Magnetism and Crystallography held in Kyoto, Japan, in September.

In studies of oxygen and hydrogen adsorption on a nickel crystal, Germer and MacRae found that after a monolayer of oxygen had been adsorbed, nickel atoms diffused to the surface, producing an orderly arrangement containing either one or two oxygen atoms for each nickel atom. The arrangement containing equal numbers of oxygen and nickel atoms was found to be remarkably stable and to persist to temperatures at which nickel evaporates rapidly. They also found that oxygen can be removed easily by hydrogen at moderate temperatures and that hydrogen can be removed by slight heating.

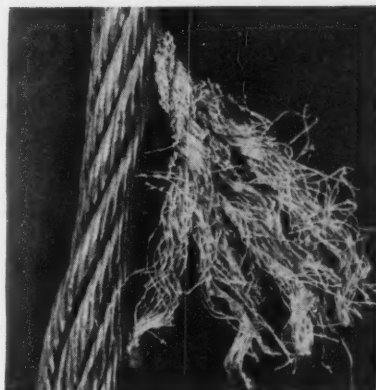


## RECORD and REPORT

### Swabbing Line's Plastic Core Resists Down-Hole Corrosives

A fibrous polypropylene core for oil field wire has proved its resistance to down-hole corrosives and high temperatures. It showed no deterioration (see photograph) when inspected after one year's service in a swabbing line in West Texas. During this period it was exposed to acids and temperatures to 280 F.

Devonian Well Service of Odessa, Texas, put a polypropylene core swabbing line in service in April, 1960, on its No. 10 unit for use in deep wells. The unit, which does rod-and-tubing work as well as swabbing, was used intermittently, with periods of storage for eleven months. In March, 1961, the unit was set over a deep well in Pecos County to swab through 3½-inch drill pipe almost continuously for four weeks down to 13,500 feet handling 121,000 gallons of 15 percent hydrochloric acid and jelled acid, all preheated to 180 F. These acids were pumped into the well and then swabbed back immediately. Four times the usual quantity of inhibitor was added to the acid. Also handled were 145,000 gallons of jelled water frac sand. Bottom-hole temperature was 280 F for the well.



**POLYPROPYLENE CORE**, washed free of grit and broomed out, shows no deterioration from down-hole corrosives and high temperatures during one year's service in an oil well swabbing line in West Texas.

Inspection of the line after this service revealed no deterioration of the core.

The polypropylene core is a development of U. S. Steel's American Steel and Wire Division, Rockefeller Building, Cleveland 13, Ohio, to end costly wire failures. Corrosion of the core through contact with acids, salt water, hydrogen, sulphide gas or sour crude is a major cause of premature wire line retirements in the oil industry. If the core, which holds the steel strands of the line in position, deteriorates, the strands stretch, flatten out or abrade each other. These aberrations eventually make the wire unsafe mechanically and its use a dangerous risk financially.

### India Surveying Interest In Corrosion Conference

India is exploring the possibility of holding a conference on the corrosion of metals in November, 1962.

Letters to various corrosion groups have been mailed to assess the response to such a meeting at the Defense Research Laboratory, Kanpur, India, under the auspices of the Ministry of Defense and the Council of Scientific and Industrial Research. Conducting this pre-conference survey is J. N. Nanda, Director, Defense Research Laboratory (Stores), Box 320, Kanpur, India.

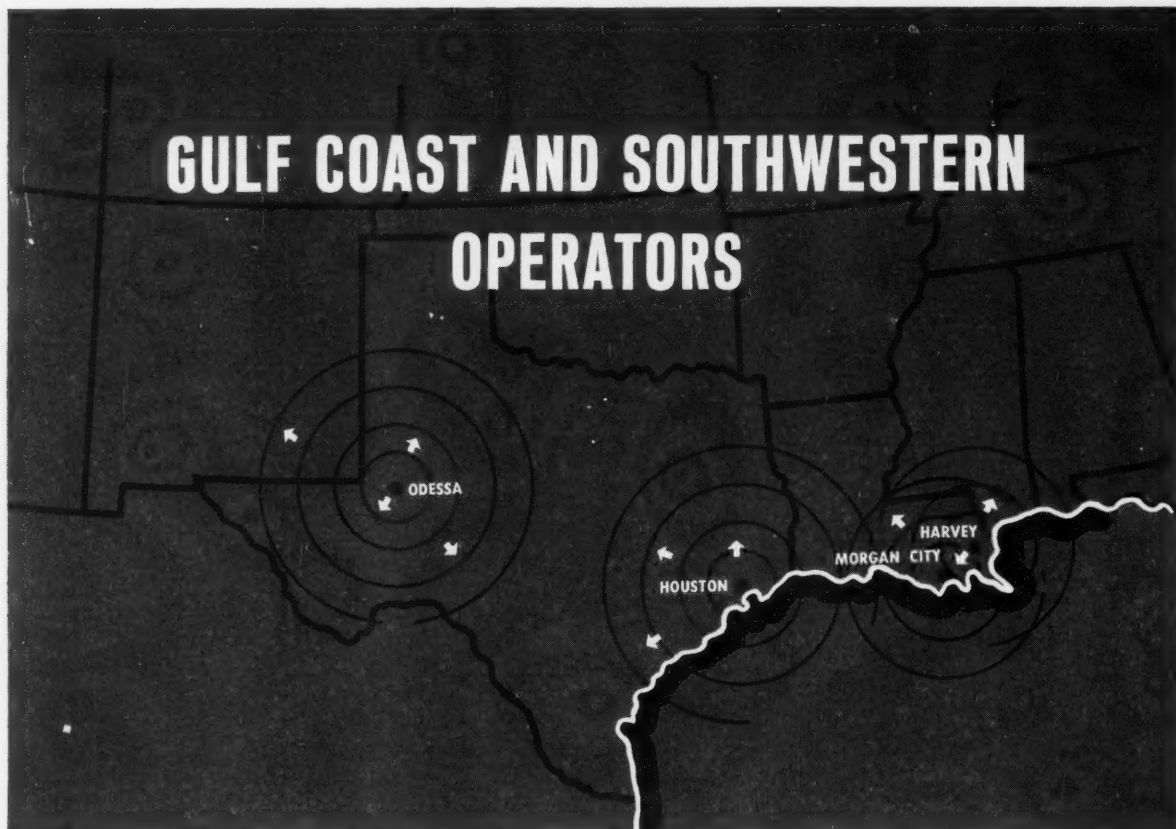
Mr. Nanda reports that the Council of Scientific and Industrial Research has formed an All India Coordinating Committee for corrosion research to promote, plan, coordinate and support corrosion research.



**RECEIVING AN EPOXY-PHENOLIC PAINT JOB** is retired Army duck now being used by eight college students from New York and New Jersey on a 27,000-mile "Operation America" goodwill tour through 17 Latin American countries this year and next. En route south of the border, the self-styled Peace Corpsmen stopped in St. Louis to have the duck protected against jungle weather. While Charles Grisby of Plas-Chem Corporation sprays, one of the students strums "Hard Travelin'" on his guitar. The tour is being sponsored by Rotary International.



## GULF COAST AND SOUTHWESTERN OPERATORS



**Plastic Applicators' four strategically located pipe-coating plants can help you cut tubing inventories, speed coated-tubing deliveries, and reduce freight costs for both new and used tubing.**

Many operators now keep their capital investment in tubing inventory low by purchasing locally from supply stores or mill stock, in quantities to meet only current needs. Usually an operator's inventory can be smaller if he can have his tubing coated quickly at a nearby plant. Such minimum-investment purchasing is especially practical for most Gulf Coast and Permian Basin operators because four conveniently located Plastic Applicators' plants at Harvey and Morgan City, Louisiana, and Houston and Odessa, Texas, give them quick delivery.

The strategic locations of these plants also help operators keep their freight costs low. (An added convenience is the full range of in-plant inspection services for new and used pipe offered by Plastic

Applicators' Pipe Inspection Division. Money-saving combination coating-and-inspection rates are available).

Call a nearby Plastic Applicators plant or sales office today for the complete story on how Plastic Applicators' conveniently located plants and on-time deliveries can help you cut costs.

### LOCATIONS:

**Main Office:** 7020 Katy Road, P. O. Box 7631, Houston, Tex., UN 9-3611. **Plants:** Harvey and Morgan City, La. Houston and Odessa, Tex.

**Sales Offices:** Midland and Corpus Christi, Tex.; Hobbs, N.M.; Tulsa, Okla.; Houma, Lafayette, New Orleans, and Shreveport, La.; Jackson, Miss.



## PLASTIC APPLICATORS, INC.



## BOOK NEWS

**Paint Manual.** Second Edition. 262 pages, 4 1/4 x 7 1/4 inches, flexible. 1961. Bureau of Reclamation, U. S. Dept. of Interior, U. S. Govt. Printing Office, Washington 25, D. C. Per copy, \$1.75. A handbook prepared for the information of the bureau's personnel concerned with painting.

Contents include: Paints and paint materials, pigmented, clear; bituminous and others, accessory materials. Wood painting, selection, surface preparation, paint preparation, application, maintenance, wood preservation. Metal painting, corrosion, coating selection, surface preparation, paint preparation, application, handling and storage of painted metals, maintenance painting.

Concrete and plaster, miscellaneous surfaces, selection, surface preparation, paint preparation, application and maintenance.

Other sections cover inspection, safety and care of materials. A list of specifications is appended. There is a short alphabetical subject index.

**Metallic Fatigue.** By W. J. Harris. 331 pages, 6 x 9 inches, cloth. 1961. Pergamon Press, Ltd., 122 East 55th St., New York 22, N. Y.; also Headington Hill Hall, Oxford, 4 & 5 Fitzroy Square, London W.1; 24 Rue des Ecoles, Paris 5; Kaiserstrasse 75, Frankfurt am Main, Germany. Per copy, \$12.50.

A comprehensive survey of the whole field of metallic fatigue with emphasis on aircraft structures. Included are sections on stress concentration, alleviation of stress concentration, frequency parameters, corrosion, fretting fatigue, crack propagation, statistics and standard aircraft processes.

Each section has appended references, which for the whole book number 376. There is an alphabetical subject and an alphabetical author index. The book is liberally illustrated and contains numerous graphs and tabulated data.

**Twenty-Year Atmospheric Corrosion Investigation of Zinc-Coated and Uncoated Wire and Wire Products.** By Fred M. Reinhart. 141 pages 6 x 9 inches, hard paper. June, 1961. American Society for Testing Materials, 1916 Race St., Philadelphia 3, Pa. Per copy, ASTM members, \$5.50; non-members, \$4.40.

Results of 20-year tests on zinc-coated copper bearing and bare steel; lead and copper-coated steel wire and wire products at 11 sites located in a variety of environments in the United States are reported. The samples consisted of wires, barbed-wires and fabricated materials such as fences, wire-strand and chain-link fences. Among the special samples were 18-8, 12-14 Cr cold drawn and air-quenched wires.

Extensive data are given on the materials in the test, the testing program, details and techniques of examination. Included are photomicrographs of representative samples, accompanied by tabulated data pertinent thereto. Tensioned and untensioned specimens were tested.

Extensive tabulated data are given on the individual lots, types of coatings, and performance at the several locations. Computed are average corrosion

(Continued on Page 40)



ONE of the new, large monomer cast nylon shapes produced by The Polymer Corporation is 4 1/2-foot gear being discussed by Polymer's President Louis L. Stott, left, and Vice President Ralph E. James.

## Large Nylon Forms Produced by Casting Caprolactam Monomer

Large nylon shapes not possible by extrusion or injection molding are possible by monomer casting, according to The Polymer Corporation, Reading, Pa.

Parts of unlimited thickness can be formed by casting melted caprolactam monomer at atmospheric pressure. Induction and extrusion molded nylon parts, made from powders of polymer which cost twice as much as monomer, are limited to thicknesses of 3/4 to 1 1/2 inches and 3 to 4 inches respectively, Polymer says.

The Polymer Corporation, which has the exclusive right to use the process in the field of casting nylon shapes, markets the monomer castings as MC nylon in various mill shapes including plate, rod and tubular bar.

## Russia's Corrosion Research Equals Western World's

Russia's corrosion research is on a par with the Western world's. Also, there is no evidence that the Russians are on the verge of a major breakthrough in the field. This is the evaluation of a survey by the U. S. Department of Commerce of 1500 references from Russian technical literature for the period 1950-60.

Published in July, 1961, the 143-page survey, titled Soviet Research on Corrosion of Special Alloys, is available for \$2.75 from the Office of Technical Services, Business and Defense Services Administration, U. S. Department of Commerce, Washington 25, D. C.

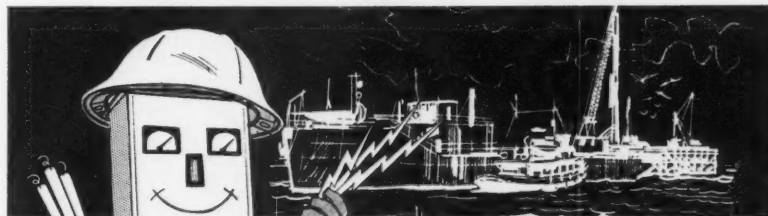
Information sources of the survey, concerned particularly with materials used in constructing aircraft and nuclear reactors, included the Abstract Card Service of the National Association of Corrosion Engineers, Chemical Abstracts and the USSR's Referativnyi Zhurnal. Other sources were the Library of Congress' Monthly List of Russian Accessions and the periodical Technical Translations published by the U. S. Department of Commerce's Office of Technical Services.

## Petroleum Group to Meet In Chicago Nov. 13-15

The American Petroleum Institute will hold its 41st annual meeting in Chicago November 13-15. Convention headquarters will be in the Conrad Hilton Hotel with sessions also being conducted in the Pick-Congress and Palmer House Hotels. Approximately 6500 are expected to attend.

U. S. Senator A. S. Mike Monroney of Oklahoma will address the opening session Monday, November 13. Assistant Secretary of the Interior John M. Kelly will address the second general session Wednesday, November 15.

LET **Coreco** WORK FOR YOU 24 HOURS A DAY TO PROTECT YOUR OFFSHORE EQUIPMENT AGAINST COSTLY CORROSION . . .



Two-folded Coreco protection pays for itself many times. Whether your problem is better solved by rectifiers or magnesium anodes, our engineers have the knowledge to determine lowest overall installation and operating costs. It costs you nothing to check with Coreco engineers.

**Coreco**  
Write or phone today for  
COSTS • SURVEYS • DESIGNS  
INSTALLATIONS • MATERIALS  
**Corrosion Rectifying Co., Inc.**

5310 ASHBROOK • MO 7-6659  
HOUSTON 36, TEXAS



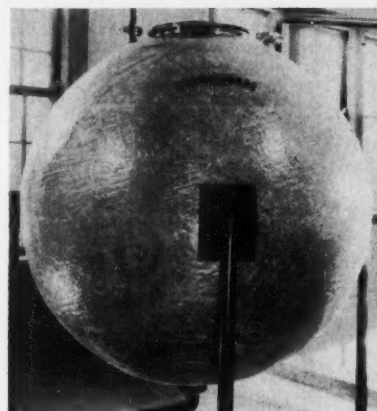
## Four Firms Combine Work on Platinized Titanium Electrodes

Four international firms have completed agreements for the development, production and sale of platinized titanium electrodes for use in electrochemical processes such as chlorine production and cathodic protection.

Engelhard Industries, Inc., 113 Astor St., Newark 2, N. J., has been named licensee under United States, Canadian and Mexican patents for the manufacture and sale of the electrodes. The three other companies involved are Im-

perial Chemical Industries, Ltd., of England, Amalgamated Curacao Patent Company of Curacao and Magneto-Chemie N. V. Schiedam, Holland. These companies will cross license under their patents and collaborate on developing additional uses of the electrodes.

The companies expect that the greatest use for the electrodes will be in large scale production of chlorine by brine electrolysis. Possible uses include electrolytic manufacture of other chemicals, conversion of sea water and brackish water to fresh drinking water by electrodialysis and cathodic protection against corrosion for steel ships, bridges and other structures, tanks and chemical equipment. Other uses are electroplating, hypochlorite generation, electrophoresis and fuel cell electrodes.



GLASS REINFORCED polyester tank designed for storing or processing chemicals is marketed by Justin Enterprises, Inc., 3755 Edwards Road, Cincinnati 9, Ohio. Special bisphenol A polyester resin used in fabricating the tank is more resistant to prolonged contact with most acids, alkalis and bleaches at elevated temperatures than general purpose or other polyesters, Justin says. The tank, called a Chemisphere, is available in diameters of 6 feet and 8 feet with capacities of 847 and 2009 gallons.

## POSITIONS WANTED and AVAILABLE

Active and Junior NACE members and companies seeking salaried employees may run two consecutive advertisements annually without charge under this heading, not over

35 words set in 8 point type. Advertisements to other specifications will be charged for at \$12.50 a column inch.

### Positions Wanted

Corrosion Supervisor with major oil company and 12 years' corrosion experience (pipelines, gas and LPG plant, production, marine craft) desires relocation Arizona, California. Sales or engineering. Top references. 1301 Thurber Place, Tucson, Ariz.

Chemist B. S., Master's courses completed metallurgy. Worked with, studied corrosion. Same company; Laboratory, development metal tubing 6 years; supervisor photoetching department 5 years, now closed. 3, married, family. Prefer Northern Third U. S. CORROSION, Box 61-24.

### Positions Wanted

Consulting Chemist with worldwide reputation on paints, lacquers and allied coatings available for specifications, sales service, trouble shooting, literature research and formulation. Expert on corrosion problems. Creative, sales-minded, experienced writer and speaker. CORROSION, Box 61-26

Sales Manager and/or Corrosion Engineer. 15 years experience in the corrosion field. Specialized during the past 6 years as sales manager for firms dealing with pipeline coatings and cathodic protection. Excellent record. Desire West Coast. CORROSION, Box 61-23.

### Positions Available



**CHEMICAL  
ENGINEER  
and  
CHEMIST**

#### CORROSION CHEMISTRY

**Chemical Engineer:** Experience desirable but not necessary. Excellent opportunity for a recent college graduate interested in beginning a career in corrosion engineering including corrosion research, selection of materials of construction and consultation on design of new equipment.

**Chemical or Corrosion Engineer or Chemist:** Knowledge of corrosion resistant and mechanical properties of metals and alloys as well as practical experience with corrosion problems in petroleum refinery or chemical plant equipment necessary. Will be responsible for laboratory corrosion studies and investigation of refinery and petrochemical corrosion problems. Opportunity to grow with small expanding group.

Outstanding Benefits - Salary Open

Send Resume To —  
ROBERT A. MATTESON

**SUN OIL COMPANY**  
1608 Walnut Street Philadelphia 3, Pa.

### Positions Available

## CORROSION CHEMIST

Career opportunity for chemist with minimum of 2-3 years experience in development of corrosion inhibitors for petroleum industry, either production or refining. Work in modern new laboratory for company that pioneered the Tretolite line of KONTOL Corrosion Inhibitors for the petroleum industry.

MS or PhD degree in Chemistry, Metallurgy, or Chemical Engineering. All replies held in strict confidence. Write to:

Director of Research

**PETROLITE  
CORPORATION**

369 Marshall Avenue / Saint Louis 19, Missouri

## BOOK NEWS

(Continued From Page 39)

rates, time to rust, average losses of zinc, effects of seasons of the year, effect of application method on zinc coating performance and others.

**The Practice of Anodic Oxidation of Aluminum.** (In German) By Walther W. G. Hubner and Ad. Schiltknecht. 431 pages, 6 x 8 7/8 inches, cloth. 1961. Aluminum Verlag GMBH, Jagerhofstrasse 29, Dusseldorf, Germany. Per copy, DM 36.

An exhaustive treatise on the subject, profusely illustrated and diagrammed. Contents include: Operations, chemical procedures, construction and selection of materials, installation, mechanical pretreatment of parts for anodic oxidation, operation techniques, research and typical defects encountered in anodically oxidized surfaces.

There are 87 literature references and an alphabetical subject index. Advertisements of suppliers and equipment manufacturers are carried at the end of the book.

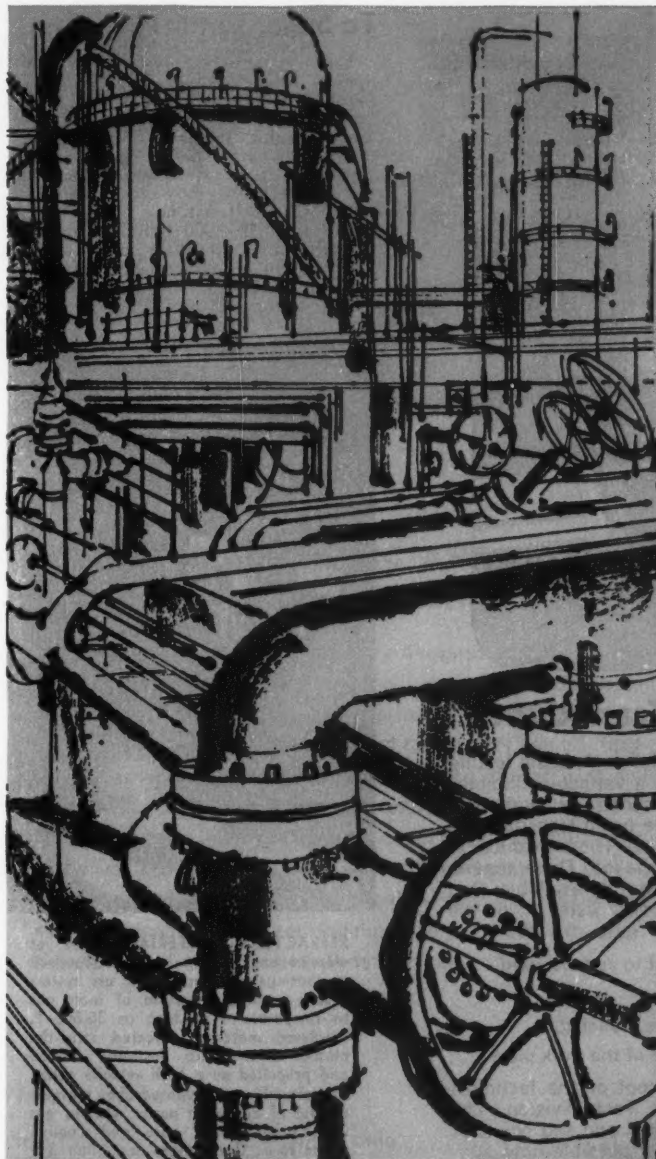
**De Corrosieweerstand van Thermisch Verzinkt Staal.** (Corrosion Resistance of Hot-Dipped Galvanized Steel). In Dutch. 99 pages, 5 3/4 x 8 1/2 inches, paper. 961. Stichting Doelmatig Verzinken, Jan van Nassastraat 93, s'Gravenhage, Holland. Availability not indicated.

Dutch version of a similar work previously published in English, Italian, German and French. Of the 140 references listed not one is from CORROSION.

The contents include characteristics of the coatings, atmospheric corrosion, corrosion in water, corrosion in chemical-contaminated water. There is an alphabetical subject index.



**now... longer life,  
improved performance  
for pipelines, crude units...  
with Unicor**



Are you aware of the tremendous difference a small amount of Unicor can make in pipelines and crude units?

This film-forming, oil-soluble inhibitor prevents all kinds of corrosion. Wherever Unicor has plated out on a surface, it gives protection to tanks, vessels and pipelines whether full, part-full or empty.

By adding a small amount of Unicor to your product—10-20 parts to a million—you prevent product contamination, profit-robbing corrosion; assure maintenance of full-flow capacity and output.

Furthermore, use of Unicor substantially reduces filter cleaning and replacements, scraping operations, power costs and expensive downtime.

What Unicor does for tanks and pipelines it also accomplishes in crude units and other refinery equipment. For detailed information, write to our Products Department.



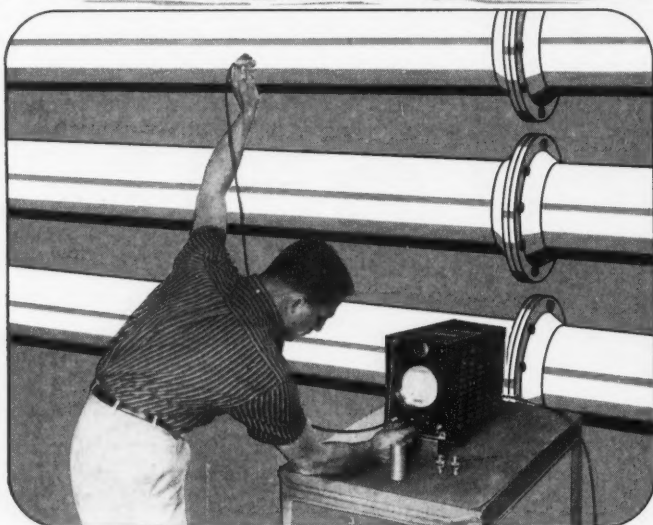
**UNIVERSAL OIL  
PRODUCTS COMPANY**

30 Algonquin Road,  
Des Plaines, Illinois, U. S. A.

# UNICOR®



# ULTRASONIC VERSATILITY PLUS!



## The Variable Angle Beam Transducer

This new transducer has been specially engineered for angle beam testing with the SONORAY® flaw detector. It incorporates a variable collimator designed to intensify the ultrasonic beam when needed. In addition to standard internal flaw detection, the variable angle beam transducer is also suitable for weld inspection and thickness gaging. The transducer is interchangeable in order to make the frequency fit the job. There are two versions of the variable angle beam transducer presently available: One for continuous water flow and the other with stationary water inside the shoe. The outstanding advantages are:

- Continuously adjustable for all angles, from straight to surface wave.
- Interchangeable transducer and beam collimators.
- Suitable for high temperature work and rapid surface scanning.
- Selection of shoes, flat or curved, to fit the surface of the work piece.

The variable angle beam transducer is further proof of the technical ingenuity and know-how of Branson's Ultrasonic Test Division. The next time you have a testing problem call BRANSON and see how fast BRANSON will find the best solution in the shortest possible time.

**BRANSON INSTRUMENTS, INC.**  
SINCE 1946 — THE RESPECTED NAME IN ULTRASONICS  
Ultrasonic Test Division  
Brown House Road, Stamford, Conn.

## Monsanto to Build Plant in Augusta, Georgia

Monsanto Chemical Company's Inorganic Chemicals Division will begin construction early next year of a plant at Augusta, Ga., to produce phosphoric acid and sodium tripolyphosphate. Production is scheduled to begin the first part of 1963.

Monsanto says locating the plant at Augusta will enable it to expand marketing services to the Southeast's fast growing detergent and metal industries.

## Visco Moves Headquarters To Sugar Land, Texas

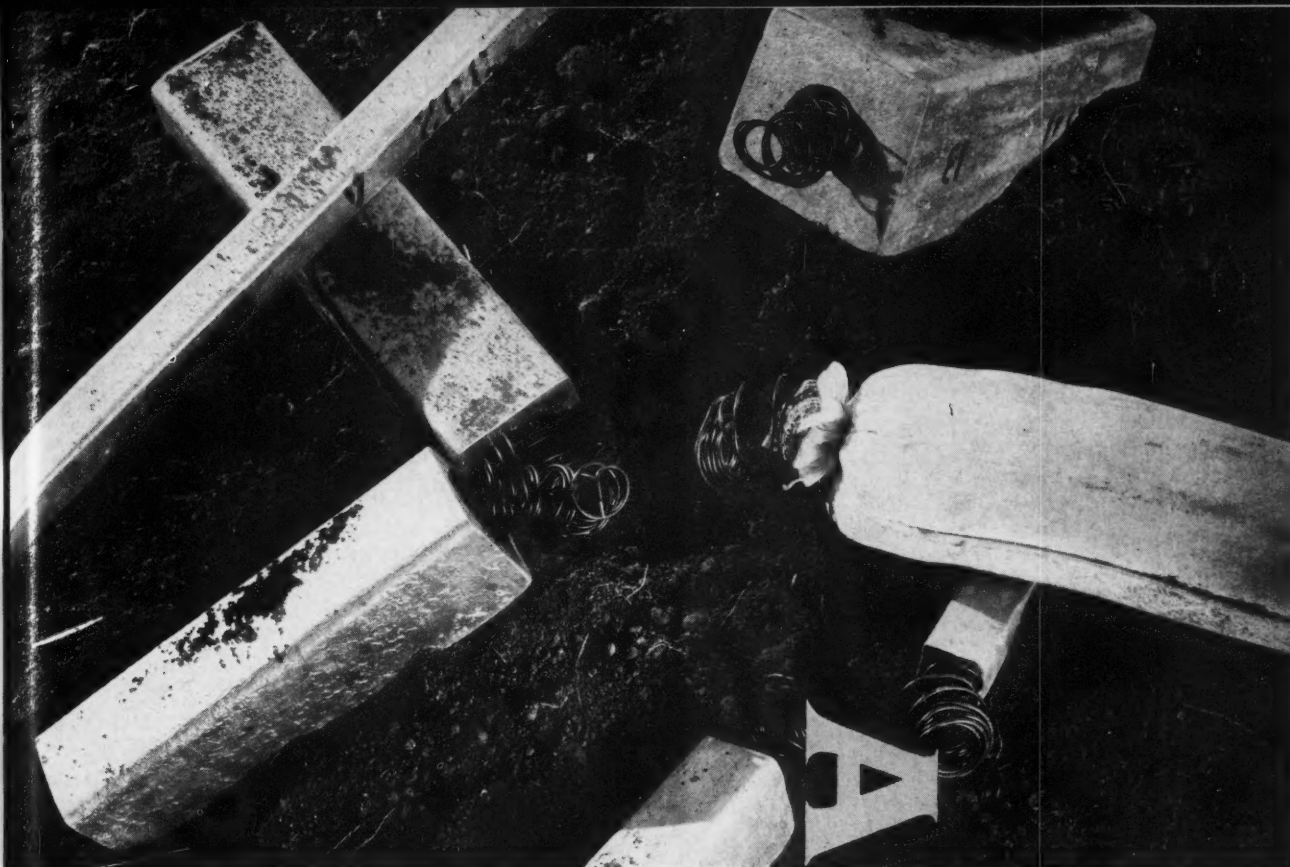
Visco Products Company formally opened its new offices and laboratory September 15 at Sugar Land, Texas, twenty miles southwest of Houston. Visco, which produces chemicals for the oil industry, began manufacturing operations in Sugar Land in 1933. Until the recent move, however, its general office was in Houston.

The new \$750,000 building to house the office and laboratory contains 25,000 square feet of floor space, of which 14,000 square feet will be utilized by the laboratory.



REFRACTORY MATERIALS such as alumina and tungsten can be deposited as coatings with an electric arc system that generates a stream of inert gas to temperatures as high as 30,000 F. Powdered materials injected into the plasma stream are instantly melted and propelled as a high velocity spray. Console, shown in photograph, provides control of electrical power, plasma gas flow, powder feed rate and cooling water flow. Gun weighs less than 3½ pounds. The console and gun are components of the Avco PlasmaGun System marketed by Avco Corporation, 201 Lowell Street, Wilmington, Mass. System also includes a power supply, a water-wash spray booth and such other cables and feed-tube assemblies as may be required for specific applications.





*Corrosion control positive:*

## **FEDERATED GALVANIC ANODES** and other non-ferrous protective materials

Federated galvanic anodes, specially designed to protect pipelines and other buried structures, are just one of the wide range of Federated materials to control corrosion. Federated's Corrosion Advisory Service can recommend the best for you . . . magnesium or zinc anodes; lead sheet, pipe, and fittings; zinc and zinc alloys for galvanizing; copper and aluminum alloys; and plating materials that include nickel, copper, lead, cadmium, zinc and silver anodes, nickel salts and addition agents for plating baths. For complete data, write or call—Federated Metals Division, American Smelting and Refining Company, 120 Broadway, New York 5, N. Y. or a nearby Federated sales office.

AMERICAN SMELTING AND REFINING COMPANY

# ASARCO

**FEDERATED METALS DIVISION**

### *Where to call for information:*

**ALTON, ILLINOIS**  
Alton: Howard 5-2511  
St. Louis: Jackson 4-4040

**BALTIMORE, MARYLAND**  
Orleans 5-2400

**BIRMINGHAM, ALA.**  
Fairfax 2-1802

**BOSTON 16, MASS.**  
Liberty 2-0797

**CHICAGO, ILL. (WHITING)**  
Chicago: Essex 5-5000  
Whiting: Whiting 826

**CINCINNATI, OHIO**  
Cherry 1-1678  
**CLEVELAND, OHIO**  
Prospect 1-2175  
**DALLAS, TEXAS**  
Adams 5-5034  
**DETROIT 2, MICHIGAN**  
Trinity 1-5040  
**EL PASO, TEXAS**  
(Asarco Mercantile Co.)  
3-1852  
**HOUSTON 29, TEXAS**  
Orchard 4-7611

**LOS ANGELES 23, CALIF**  
Angelus 8-4291  
**MILWAUKEE 10, WIS.**  
Hilltop 5-7430  
**MINNEAPOLIS, MINN.**  
Tuxedo 1-4109  
**NEWARK, NEW JERSEY**  
Newark: Mitchell 3-0500  
New York: Digby 4-9460  
**PHILADELPHIA 3, PENNA.**  
Locust 7-5129  
**PITTSBURGH 24, PENNA.**  
Museum 2-2410

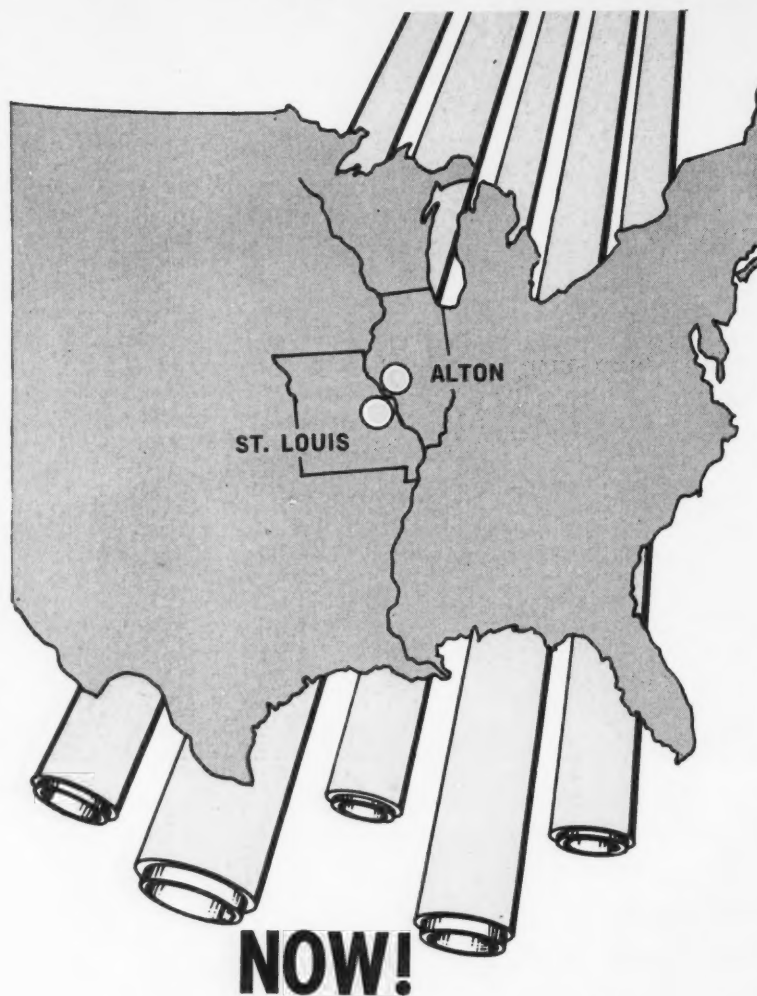
**PORTLAND 9, OREGON**  
Capitol 7-1404  
**ROCHESTER 4, NEW YORK**  
Locust 5250  
**ST. LOUIS, MISSOURI**  
Jackson 4-4040  
**SALT LAKE CITY 1, UTAH**  
Empire 4-3601  
**SAN FRANCISCO 24, CALIF.**  
Atwater 2-3340  
**SEATTLE 4, WASHINGTON**  
Main 3-7160

**WHITING, IND. (CHICAGO)**  
Whiting: Whiting 826  
Chicago: Essex 5-5000

**IN CANADA: Federated Metals Canada, Ltd.**  
Toronto, Ont., 1110  
Birchmount Rd.,  
Scarborough, Phone:  
Plymouth 73246

**Montreal, P.Q., 1400**  
Norman St., Lachine,  
Phone: Melrose 7-3591





**from SPI's new Alton, Illinois Plant**  
comes **STANDARD X-TRU-COAT**

Standard Pipeprotection's new plant at Alton, Illinois has been shipping Standard X-Tru-Coat pipe to the Southwest and West since early July. Sizes available include  $\frac{3}{4}$ " Nom. through  $4\frac{1}{2}$ " O.D.

X-Tru-Coat high density polyethylene plastic coating for pipe is produced under the DeKoron process — Pat. Nos. 2,447,420 and 2,467,642 — and is extruded on pipe over a pressure sensitive adhesive.

Standard Procedures assuring top quality prevail at the Alton, Illinois plant, as they have for many years at SPI's coating and wrapping plant in St. Louis. In-Transit privileges are available at both plants from any pipe mill.

Standard Pipeprotection, with the introduction of X-Tru-Coat, has continued to contribute to the progress of the oil and gas industry.



**standard pipeprotection inc.**

3000 SOUTH BRENTWOOD BLVD. • ST. LOUIS 17, MISSOURI

Write for complete information and  
for Price List Number X-1.

## IBM Seals Thousands of Tiny Diodes at One Time With Glass

Sealing thousands of microminiature diodes simultaneously, instead of one at a time, against moisture and other atmospheric contaminants is achieved by a glass film deposition technique developed by International Business Machine Corporation, Box 380, Poughkeepsie, N. Y. IBM says the new sealing method holds promise of overcoming many cost and reliability problems inherent in producing microminiature devices.

The diodes, so small that a thousand are cut from a silicon wafer the diameter of a nickel, previously were separately encapsulated in plastic or glass made at relatively low heating temperatures or enclosed in hermetically sealed metal containers.

Now, after the diodes are fabricated on silicon wafers and oxidized, glass powder is applied to the wafers and fired at more than 1500 F. The result is a microscopically thin film of chemically resistant glass with a smooth, pin-hole free surface.

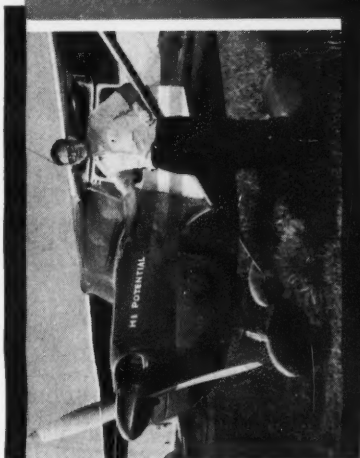
The wafers are then cut ultrasonically into tiny diodes, each retaining its glass seal. Electrical contact to the diode is made through a small hole etched through the glass and oxide.



**GLASS** a thousand times thinner than a window pane protects several hundred diodes on section of silicon wafer at IBM Laboratories, Poughkeepsie, N. Y. Glass powder fired at 1500 F produces a chemically resistant seal for diodes. A full size wafer, the diameter of a nickel, is ultrasonically cut into more than a thousand diodes, each retaining its permanent glass seal.

In the production of iron and steel in 1960, steel companies in the U. S. consumed 114.5 million tons of iron ore, 71.4 million tons of coking coal, 25.9 million tons of limestone and 52.1 million tons of scrap.





**CPS offers you...**

*The largest, most  
experienced  
engineering staff...  
The largest stock  
of materials...  
The most modern  
construction  
equipment.*

ANODES, Magnesium, Zinc, Aluminum, Graphite, Platinum-Titanium; BACKFILL, Coke or Clay; THERMO-ELECTRIC GENERATORS; RECTIFIERS; POLYKEN and SCOTCHRAP PLASTIC TAPE COATINGS; ENGINEERING, Survey, Design, Installation.



**cathodic protection service**

JA 5-1981

Houston 5, Texas

PITTSBURGH  
4 Delmar Ct.  
Delmont, 468-4303

NEW ORLEANS  
1627 Felicity  
Jackson 2-7316

TULSA  
2570 S. Harvard  
Riverside 2-7393

CORPUS CHRISTI  
1620 S. Brownlee  
Tulip 3-7264

ODESSA  
5425 Andrews Hwy.  
Emerson 6-6731

LOS ANGELES  
7531 Muller Street  
Downey, Phone TO 2-2045

**BY AIR... BY WATER... BY GOLLY!**

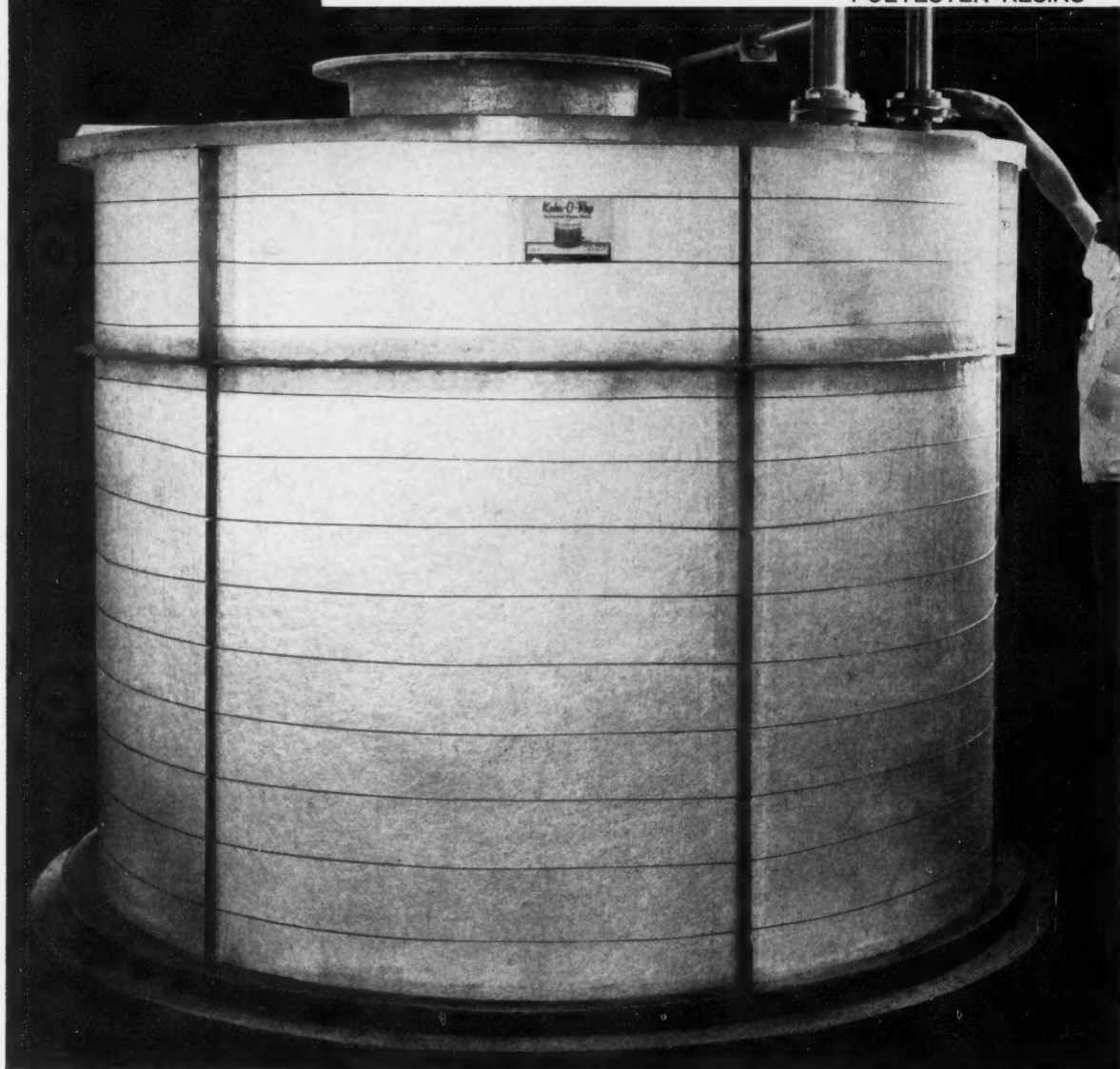
*CPS delivers  
Turnkey Cathodic Protection*



CYANAMID

## CORROSIONEERING WITH LAMINAC®

POLYESTER RESINS



### Problem: Get a 7' tank through a 3' door

**ANSWER: LAMINAC!** For years, Laminac has proved successful in resisting the corrosive action of industry's strongest chemicals. In the case of the North Tonawanda water department, however, versatile Laminac did much more than provide corrosion resistance. It helped the city avoid the high cost of breaking down a wall in order to install a new 7' diameter storage tank.

How? A Kabe-O-Rap tank, made of glass-reinforced Laminac and stainless steel cables by Metal Cladding, Inc., was assembled inside the building from pre-molded sections. Result: Costs were cut in half.

What's more, North Tonawanda's large Kabe-O-Rap tank, as well as their 3' version, will fight off the acid attack of the city's 23% hydrofluosilicic acid indefinitely. They need no

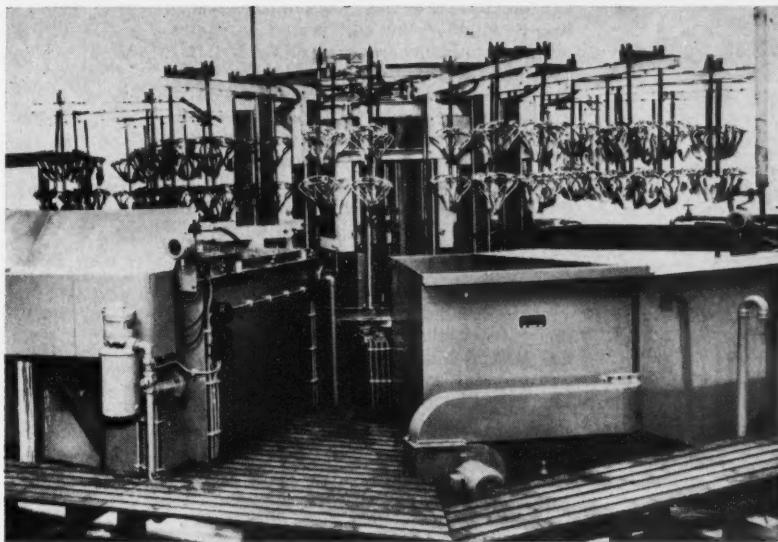
painting or other costly maintenance. Size and location of outlets can be changed. If repairs become necessary they can easily be made by patching with Laminac and fibrous glass.

Learn more about Laminac, the material that has been solving industry's toughest corrosion problems. For details or technical assistance, contact any Cyanamid office listed below.

**AMERICAN CYANAMID COMPANY • PLASTICS AND RESINS DIVISION** • Wallingford, Connecticut. Offices in: Boston • Charlotte • Chicago • Cincinnati • Cleveland • Dallas • Detroit • Los Angeles • Minneapolis • New York • Oakland • Philadelphia • St. Louis • Seattle. In Canada: CYANAMID OF CANADA LIMITED, Montreal • Toronto.

CYANAMID





COMPLETELY AUTOMATED machine for galvanizing and other surface treatments of metals has been placed in production by a Netherlands firm and will soon be exported to the United States.

## Dutch Firm Making Automated Machines For Galvanizing

A completely automated machine which carries out the entire cycle of operations required for galvanizing and other surface treatments of metals has been placed in production by a Netherlands firm and will soon be exported to the United States, according to the Netherlands Trade Commission, 10 Rockefeller Plaza, New York 20, N. Y.

The manufacturer, Metallic Industry N.V. of Loosdrecht, The Netherlands, reports the installation performs the following sequence of operations: suspension and removal, electrolytic degreasing, cold rinsing, acid bath, cold rinsing, zinc, cadmium or nickel plating, cold rinsing, passivating (or acid bath), cold rinsing, decolorizing (or chromium or brass plating), cold rinsing and hot rinsing.

The machine, circular in shape and to be available in various models with diameters of 13 to 19½ feet, is 8 feet high and divided into 16 sections. Sections 6 to 10 form one large bath in which the actual treatment of galvanizing or cadmium or nickel plating occurs.

## Beryllium Conference Set December 4-5 at N.Y.U.

A two-day conference on beryllium metallurgy will be held December 4 and 5 at New York University's Washington Square Center.

The program, intended for engineers from industrial, research and governmental organizations, will cover beryllium as a key metal in missile and rocket research along with such other topics as purification, mechanical metal-

lurgy, corrosion and structural applications. Sixteen papers are scheduled.

The conference will be presented by the department of metallurgy and materials sciences of NYU's College of Engineering and the university's Bureau of Conferences and Institutes. Sponsoring the conference are the Beryllium Corporation of America and the Brush Beryllium Company.

## A.S.T.M. Changes Name

The American Society for Testing Materials has changed its name to American Society for Testing and Materials, the "and" having been added to emphasize the society's research work in seeking knowledge of the nature of materials.

The ASTM, which was founded in 1898, now has almost 11,000 members. In addition about 7,000 engineers and others serve as representatives of company members on the society's 87 technical committees.

## Lost Wax Casting Used To Make Bone Substitutes

Investment or lost wax casting is often the only economical means of fabricating prosthetic devices used by surgeons to substitute for damaged bones and joints, Casting Engineers, 2323 North Bosworth Avenue, Chicago, Ill., reports.

Alloys used in these castings must be impervious to body chemicals, must exhibit uniform grain structure and high density and must pass 100 percent x-ray and zygo inspection.

Typical is a prosthesis for replacement of fractured joints in hip surgery. It is cast from a cobalt-base alloy (AMS 5385) equivalent to Stellite 21, a material often used in high performance jet engine blades. The alloy, Casting Engineers says, is virtually impossible to machine in such intricate configurations as the hip prosthesis. The as-cast surfaces normally require only light polishing before being used.

## Engineering Council Moves To New Engineering Center

Engineers Joint Council, federation of 24 national and regional engineering societies, moved into the new United Engineering Center facing the United Nations Plaza September 5, joining 18 other major engineering groups.

New quarters of EJC are at 345 East 47th St., New York 17, N. Y. This is also the new address for the organizations for which EJC is the secretariat. These include the Engineering Manpower Commission, IAESTE (International Association for the Exchange of Students for Technical Experience), The United States Committee on Large Dams (USCOLD) and the World Power Conference. EJC's newspaper, Engineer, may be addressed there also.

## Copying Device Scans . . . Reproduces on Tape

A device which can be used to reproduce facsimile copies on tape of sentences and single words has been developed by the Institute for Scientific Information, 33 South Seventeenth Street, Philadelphia 3, Pa.

With the pilot model, called a Copywriter, the operator moves the transmitting unit over the material to be copied. The text is reproduced immediately on tape, which can be pasted to paper as telegrams are.

The device was developed by the institute under a grant from the Council on Library Resources to eliminate the necessity of photographing entire pages to obtain, for example, a single chemical diagram or formula.

**Arno®**  
**PIPE-WRAP**  
**TAPE**

**Fast . . . Easy Pipe Protection**

Joint wrapping of mill coated pipe is easy, fast and sure with Arno Pipe-Wrap Tape. Its inert polyethylene backing is moisture proof, non-conductive and resistant to soil acids and alkalis. Tough and stretchy. High-tack adhesive. Write for information and free test sample.

**ARNO ADHESIVE TAPES, INC.**  
Dr. Scholl's Adhesive Tape Division  
5110 Ohio Street, Michigan City, Indiana

**MANUFACTURERS AGENTS WANTED FOR SOME SELECTED AREAS**



## GAR-LINE PENTON TANK LININGS

for High-Temperature  
Corrosion Proofing



Tailored to your  
specific needs, GAR-LINE\*  
Penton\*\* Linings can be  
applied to a variety of  
complex shapes as shown in  
these photos.



Can be applied to virtually any surface or contour to give superior, low cost protection against high-temperature corrosion. GAR-LINE Penton Tank Linings are replacing and outperforming more expensive materials in an ever-increasing number of applications.

Serviceable at temperatures up to 280°F, these efficient linings embody outstanding tensile strength, excellent dimensional stability and low water absorption. Chemically, they resist bleaching agents, solvents, plating solutions . . . in fact, all inorganic acids except fuming nitric and fuming sulfuric.

Applied by carefully selected and authorized applicators. The experience of these tank lining experts guarantees satisfactory GAR-LINE Penton installation, prevents expensive failure due to improper application. Approved applicators include:

ABRASION & CORROSION ENGRS. 1205 N. McMasters Street Amarillo, Texas	HANSZEN PLASTICS COMPANY 835 S. Good-Latimer Exprw. Dallas, Texas
ATTBAR PLASTICS 1107 Northeast 106th Street Vancouver, Washington	HEIL PROCESS EQUIPMENT CORP. 12901 Elmwood Ave., Cleveland 11, O.
BARTHEL CHEMICAL CONST. CO., INC. P. O. Box 1025, Tacoma 1, Wash.	HUNTINGTON RUBBER MILLS of Port Coquitlam B.C., Canada
BITTNER INDUSTRIES, INC. 91 Diaz St., P. O. Box 10265 Prichard, Alabama	INNER-TANK LINING CORP. 4777 Eastern Ave., Cincinnati 26, O.
BUCKLEY IRON WORKS 21 Christopher St., Dorchester, Mass.	MAURICE A. KNIGHT Kelly Ave., Akron 9, Ohio
BUFFALO LINING & FABRICATING CORP. 73 Gillette Ave., Buffalo 14, N.Y.	MERCER RUBBER CORPORATION Highway 46, Cor. Huyler Little Ferry, New Jersey
CEILCOTE COMPANY, INC. 4832 Ridge Rd., Cleveland 9, Ohio	METALWELD, INC. Scotts Lane & Abbottsford Rd. Philadelphia 29, Pennsylvania
CHEMICAL PROOF OF SEATTLE 625 Alaska Ave., Seattle, Wash.	PARKER BROTHERS, INC. 7044 Bandini Blvd. Los Angeles 22, California
ELCHEM ENGRG. & MFG. LTD. P. O. Box 249 Burlington, Ontario, Canada	PLASTIC APPLICATORS, INC. 7020 Katy Road, P. O. Box 7631 Houston 7, Texas
ELECTRO CHEMICAL ENGRG. & MFG. CO. 750 Broad St., Emmaus, Penn.	PROTECTIVE COATINGS 1602 Birchwood Ave., Ft. Wayne, Ind.
THE FABRI-FORM COMPANY P. O. Box 125, Byesville, Ohio	ROANOKE BELTING & RUBBER CO. P. O. Box 1593, 345 Center Ave., N.W. Roanoke 7, Virginia
FLORIDA CORROSION CONTROL P. O. Box 10082, Jacksonville 7, Fla.	RUBBER ENGINEERING & MFG. CO. P. O. Box 2335, Salt Lake City 10, Utah
THE FORTUNE COMPANY 1100 W. 37th St.—North Wichita 14, Kansas	RUBBER MILLERS, INC. 707 S. Caton Ave., Baltimore, Md.
GALIGHER COMPANY 545 West 8th—S., Salt Lake City, Utah	ST. LOUIS METALLIZING CO. 625 S. Sarah St., St. Louis 10, Mo.
GATES RUBBER COMPANY Denver, Colorado	L. H. SHINGLE CO. 1300 Walnut St., Camden 3, N.J.
GOLDEN PLASTICS CORP. 333 East 8th St., Oakland 6, Calif.	STEBBINS ENGRG. & MFG. CO. Watertown, New York
GOODALL RUBBER COMPANY 2050 N. Hawthorne Avenue Melrose Park, Illinois	WILLOW RUN RUBBER COMPANY 12575 Haggerty St., Bellville, Mich.

Investigate GAR-LINE Penton Tank Linings as the answer to your corrosion problems. For more information, contact the applicator nearest to you. Or, write for data on Penton; information also available on Teflon† linings for Anti-Stick or corrosive applications. Special Products Dept., Garlock Inc., P. O. Box 612, Camden 1, New Jersey.

\*Garlock Registered Trademark  
\*\*Registered Trademark, Hercules Powder Company  
†Registered Trademark, The DuPont Company

# GARLOCK



## Equipment Services

## NEW PRODUCTS

## Materials Literature

### Cleaners

"Forty Precision Finishing Operations Where You Can Cut Costs by Liqua-matte Wet Blasting" is the title of a new bulletin available from Lord Chemical and Equipment Division of Wheelabrator Corporation, 2068 South Queen Street, York, Pa. Rust removal blending directional lines, finishing dies, scale removal, deburring and degreasing are some of the operations described.

New single unit ultrasonic generator with automatic load compensation adjusts itself to variations in cleaning load, temperature of solution and tank volume, according to manufacturer, Branson Instruments, Inc., 40 Brown House Road, Stamford, Conn. Recommended for high speed cleaning of steel strip, multiple strand wire cleaning machines, long conveyorized systems and heavy duty batch operations, unit provides average power output of 3500 watts and peak output on pulses of 7000 watts. Simultaneous compensation for both frequency and impedance is said to keep acoustic energy in cleaning system at peak performance level.

A polishing and grinding machine designed to prepare fine metallographic

specimens is described in a data sheet available from Geoscience Instruments Corporation, 142 Maiden Lane, New York 3, N. Y. Specifications include 8-inch lap or polishing wheel, variable speed control in range of 80 to 1200 rpm, ½ hp d-c motor with rectifiers to convert power to alternating current, dimensions of 16 by 19¾ by 17 inches and net weight of 110 pounds.

A new high pressure wagon mounted sprayer removes grease and grime from heavy equipment and buildings with unheated water and detergents. Also it can be used to spray insecticides and liquid and dry fertilizers. Designed to spray 10 gallons per minute at gauge pressure of 500 psi or 6 gallons at 200 psi, it is marketed as Hayes Jet 500 Power Sprayer by Hayes Spray Gun Company, 98 North San Gabriel, Pasadena, Cal. The sprayer, which has no water tank, draws water from faucets, tanks or other external water sources. Chemicals do not pass through the water pump. As clear water is discharger from the pump, a vacuum created in external mixing chamber siphons chemicals from concentrate tank mounted on the chassis. Water and chemicals are automatically proportioned, mixed and carried to nozzle. Concentrate tank has polyethylene liner.

### Coatings, Organic

For steel and concrete floors, an epoxy finish formulated to improve traction and resist alkalis, caustic solutions, acids, solvents and other chemicals is marketed as Heavy Duty Grip-Deck by Fibreboard Paper Products Corporation, 475 Brannan Street, San Francisco 19, Cal.

For metal, wood and masonry, an activated epoxy coating resistant to fats, oil, syrups, soaps and most acids and alkalis is marketed as Tile-Cote by The Wilbur & Williams Co., 650 Pleasant Street, Norwood, Mass.

For protection of floors, structures and equipment subjected to abrasion or to fumes, splashes and spills of alkalis, dilute acids and industrial solvents, a polyurethane enamel is marketed as Imron by E. I. du Pont de Nemours & Company, Wilmington, Del.

Low viscosity in solutions of high solids contents is the key property of two new high purity vinyl solution resins intended for preparation of product finishes and industrial maintenance coatings, according to Union Carbide

Continued on Page 50)



**CHEMICAL PROOF FLOORS WITH A PLASTIC BLANKET**

**Steelcote**  
EPO FLOOR TOP EPOXY

**IT ROLLS ON AT  
1/4<sup>TH</sup> THE COST OF QUARRY TILE**

The largest national beverage company in its field, after study and tests, recently adopted Steelcote EPO-FLOOR TOPPING to protect concrete floors from corrosion of food acids and alkalis in its newest plant.

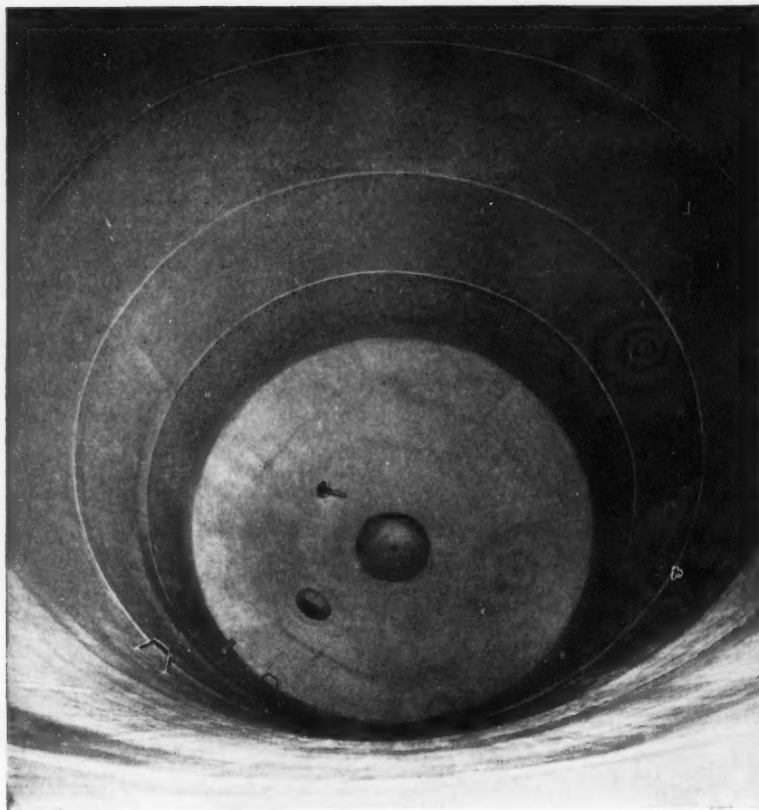
Here are the reasons:

Easy application, monolithic groutless cleanliness, resistance to acids, alkalis, moisture, strength many times that of concrete, and non-slip surface that fights abrasion.

For maximum protection at minimum cost specify Steelcote Epo-Floor Topping on your next job. For complete information write, wire or phone.

**STEELCOTE MFG. CO. • 3418 Gratiot, St. Louis 3, Mo. • Rodney, Ontario, Canada**





10429-CC

## CEILCOTE CORROSION-PROOF COROLINE 505 TANK LININGS

COROLINE 505 LININGS . . . reinforced with Type "F" glass cloth are used for handling hot detergents. Other applications include: Chemical Storage tanks, processing tanks, pickling and plating tanks, pits and foundations. Tough, durable and long-lasting, COROLINE 505 provides proven resistance to most acids, alkalis and solvents . . . and, features good temperature resistance without permitting age hardening. **EASY APPLICATION IN SHOP OR FIELD:** Applied in a "build-up" process, COROLINE 505 works easily with either trowel or brush. For steel or concrete surfaces, COROLINE 505 is generally reinforced with glass cloth. Application thicknesses vary from  $\frac{1}{32}$ " to  $\frac{3}{16}$ " depending on required operating conditions.

Send today for the  
CEILCOTE COROLINE BULLETIN  
. . . it contains all the facts.

CEILCOTE COMBINES MINDS,  
METHODS AND MATERIALS . . .  
. . . for the design and  
construction of CORROSION-  
PROOF equipment and instal-  
lations for all industries.



THE CEILCOTE COMPANY, INC. •



4874 Ridge Road • CLEVELAND, OHIO

## NEW PRODUCTS

(Continued From Page 49)

Plastics Company, Division of Union Carbide Corporation, 30 East 42 Street, New York 17, N. Y. The resins, Bake-lite VYHD and VXCC, are medium molecular weight, vinyl chloride-vinyl acetate copolymers. VYHD is unmodified. VXCC is structurally modified to impart metal adhesion properties.

### Fittings

Push-pull connect-disconnect couplings that sustain operating pressures to 3000 psi are claimed by E. B. Wiggins Oil Tool Company, Inc., 3424 East Olympic Boulevard, Los Angeles 23, Cal. Designed for electronic cooling and hydraulic systems and available in eight models, the Inst-O-Matic coupling is said to withstand vibrations of 20 G at 2000 cps. Either stainless steel or aluminum models in sizes  $\frac{1}{4}$  to 2 in ID are available.

Flexible couplings designed for service in water, oil, mild chemicals and other corrosives are manufactured by Lovejoy Flexible Coupling Company, 4949 West Lake Street, Chicago 44, Ill. Bodies are semi-steel castings with hot dipped galvanized outside collars and inside sleeves. Set screws, lock washers and retaining bolts are stainless steel. Bake-lite cushions are boiled for five days to prevent swelling, shrinking or distortion after installation.

### Gaskets

Gaskets made of Teflon molded around perforated steel disks will not cold flow or blow out, are easy to install and re-usable, according to the manufacturer, The Duriron Company, Inc., 422 North Findlay, Dayton 1, Ohio. They are marketed as Task-Line Gaskets in sizes 1,  $1\frac{1}{2}$ , 2, 3, 4, 6 and 8 inches.

A gasket which operates at temperatures from 1250 to 1900 F is reported by Garlock Inc., Main Street, Palmyra, N. Y. The new spiral wound Guardian gasket uses a ceramic paper filler which is non-flammable, inorganic and an outstanding chemical insulator, Garlock says. A new product brochure detailing various Garlock gasket materials, resistance ratings and design suggestions is available from the company.

High pressure seals and fasteners manufactured by A. P. M. Corporation, 41 Honeck Street, Englewood, N. Y., are described in a catalog available from the company. Contents include dimensional drawings, parts numbers, complete specifications and ordering instructions.

### Instruments

A 3-lb battery operated direct current potentiometer for use as an infinite impedance calibrator and measuring instrument is marketed as Model PC Pocketpot by Sensitive Research Instrument Corporation, 310 Milam Street, New Rochelle, N. Y. Accuracy is 0.05



percent. Measuring range is 0-5.100 volts with continuous resolution over a 100 division slide wire (1 millivolt per division). Current ranges from 0-1 ampere and additional voltage ranges to 500 volts can be obtained by using the instrument with manufacturer's plug-in switch controlled current-volt-box called Model PC-S. Accuracy of the two units used together is 0.1 percent of reading over the upper four-fifths of the ranges.

Non-destructive gauging of non-conductive coatings on aluminum and its alloys is possible with the Type EC Permascope developed and marketed by Twin City Testing Corporation, 533 South Niagara Street, Tonawanda, N. Y. The device also measures thickness of a non-ferrous metal on a non-ferrous base, thickness of a non-ferrous coating on a non-conductor and conductivity of a non-ferrous metal. The 110-volt a-c gauge is 9 x 6½ x 6½ inches.

An electrobalance which weighs analytical and production samples to 1.5 grams with precision of 0.1 microgram is described in a bulletin available from manufacturer, Cahn Instrument Company, 14511 Paramount Blvd., Paramount, Cal.

### Insulation

A lightweight thermal insulation made of high pressure laminate of nylon fabric and phenolic resin is described in a bulletin available from the manufacturer, Taylor Fibre Company, Norristown, Pa. Applications include rockets subjected to temperatures exceeding 4000 F for short periods. The material, called Tayloron PN, is available in

laminated sheet, molded rod and tube, rolled tube, molded shape in built-up formations and molding forms in sheets, rolls and cut squares.

Accordion-type protective sleeves of silicone coated fiberglass material resist ambient temperatures to 450 F and flex normally without cracking at temperatures to -80 F, according to the manufacturer, A&A Mfg. Company, Inc., 712 South 12th Street, Milwaukee 4, Wis. Also, on 70-hour test at 350 F in ASTM No. 1 oil, there was neither noticeable decomposition nor surface tacking, A&A says; volume change did not exceed 11 percent. A suggested application is ducts for heat and hot gas transfer between intake and exhaust of industrial furnaces.

### Lubricants

A spray-on lubricant and anti-stick agent which resists solvents and chemicals and withstands temperatures ranging from cryogenic to 500 F while imparting a coefficient of friction as low as .07 is marketed as Fluoro-Glide by Chemplast, Inc., 3 Central Avenue, East Newark, N. J. The lubricant consists of micron-size particles of fluorocarbon polymer and an adhesion promoter which combine to form a tenacious low friction dry film, Chemplast says.

For lubricating ultra precise miniature instrument bearings, a new grease so clean that no foreign matter can be detected under 500 power magnification is reported by its developer, Miniature Precision Bearings, Inc., Keene, N. H. Marketed as Minapure, the grease has

been subjected to intensive testing in corrosive atmospheres and under extremely high rpm and load conditions, the company says.

### Metals, Ferrous

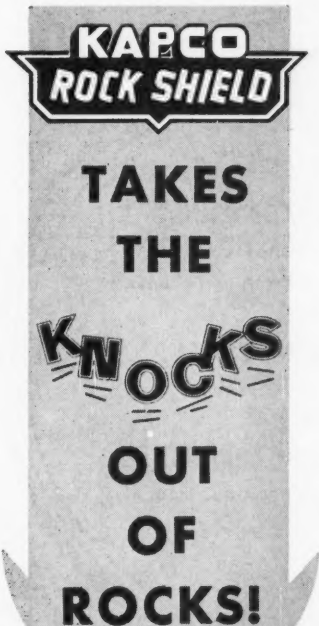
Wrought iron steps for sewage plants and manholes are discussed in 8-page bulletin from A. M. Byers Company, Clark Building, Pittsburgh 22, Pa. Bulletin explains what 4-D wrought iron is, points out advantages of galvanizing steps and illustrates typical designs of manhole ladder steps and several installations.

Satin finished wall plates of Type 302 stainless steel containing 18 percent chrome and 8 nickel are resistive to salt spray, most organic chemicals, food acids and sterilizing solutions, manufacturer says, and are recommended for hospitals, laboratories, piers, gas and chemical plants, refineries, bathrooms and kitchens. Catalog sheets and price lists are available from Bell Electric Company, 5735 S. Claremont Avenue, Chicago 36, Ill.

Ductile iron gratings for floors and outside installation are marketed by Crompton and Knowles Corporation, Worcester, Mass. Fifty percent lighter in weight than iron and steel gratings, they have greater impact resistance and strength than gray iron gratings, C&K says, and also, being lighter, are easier to install or relocate. Various designs to fit customers' needs are produced.

Two new chromium stainless steel alloys having high corrosion resistance and

(Continued on Page 52)



Lowering-in and backfilling of pipe in rocky terrain can often result in costly damage to the coating . . . but not when it is protected with Kapco Rock Shield. ■ Kapco is a strong, mastic composition board which is designed especially to resist rock impacts. Kapco saves application time, too . . . the boards are simply strapped into place with pressure sensitive filament tape or steel strapping and a section of pipe can be covered in only a few minutes. Kapco is available in a number of thicknesses to meet varying terrain conditions. ■ A Midwestern Man would be glad to show you how Kapco Rock Shield can provide positive protection for your pipelines. Contact the nearest Midwestern office today.

## MIDWESTERN PIPE LINE PRODUCTS CO.

4645 Southwest Blvd. Tulsa, Okla. HI 6-6144  
Cable Address: Mid Pipe

#### branch offices

- Durham, N. C.
- Houston, Tex.
- Chicago, Ill.
- St. Petersburg, Fla.
- Pittsburgh, Pa.
- Oklahoma City, Okla.
- Des Moines, Ia.
- New York, N.Y. (export)
- Caracas, Venezuela



## NEW PRODUCTS

(Continued From Page 51)

outstanding fabricating and finishing qualities are reported by their developer, Universal-Cyclops Steel Corporation, Bridgeville, Pa. Automobile manufacturers are using both alloys for 1962 auto parts such as moldings and hub caps, U-C says. The two grades, both with molybdenum additions, are Uniloy 430Mo and Uniloy 435Mo, the 435 grade containing an element to control roping. They are available in production quantities in a full range of strip and wire sizes.

### Metals, Non-Ferrous

Identification numbers have been given to more than 100 commercially important wrought coppers and copper alloys. For example, Oxygen Free Certified Copper is now Copper 101; Cadmium Copper is now Copper Alloy 162. Copies of the industry adopted classification are available from Copper & Brass Research Association, 420 Lexington Avenue, New York 17, N. Y., whose Standards Committee drew up the numbering system.

Bibliography containing 107 abstracts on nickel carbonyl for production of nickel and nickel alloys, for deposition of nickel coatings, as gasoline additives, etc., for period 1891-1955 is available from International Nickel Company's

Industrial Chemicals Section, 67 Wall Street, New York 5, N. Y.

New identification numbers have been assigned to alloys of Huntington Alloy Products Division, The International Nickel Company, Inc., Huntington 17, W. Va. Copies of the new numbering system are available from the company.

Production, Properties and Uses of Lead Cable Sheathing is the title of a new booklet available from the Lead Development Association, 34 Berkeley Square, London, W. 1, England.

### Packing

Leather packings for hydraulic and pneumatic service are described in a brochure available from Garlock, Inc., Palmyra, N. Y. Available in various forms including U, cup, Vee, flange packings, gaskets and washers and impregnated according to medium to be encountered in service, the leather packings have tensile strength of 3000 to 3500 psi, pressure range of vacuum to 100,000 psi, pH range of 3 to 8.5 and temperature range of -320 to 200 F. Leather has a low coefficient of friction, is non-scoring and non-abrasive and has long shelf life, Garlock says.

Packing clinics are being sponsored by Garlock, Inc., Palmyra, N. Y., for engineering, purchasing and maintenance personnel. Garlock has provided each of its 15 district sales offices with a series of 43 colored slides illustrating correct packing procedures, case his-

tories and recent packing designs. Clinics can be arranged by contacting either Garlock home offices or its sales offices.

For centrifugal and rotary shafts, valve stems, expansion joints and reciprocating rods, plungers and rams operating at temperatures -90 to 500 F, Garlock, Inc., Palmyra, N. Y., has developed two new Teflon impregnated braided packings. Garlock 5881 is for use in strong caustics, acids, alcohol, lime solutions, waxes, chlorine and film coating solvents; it is Teflon-impregnated blue asbestos. Garlock 5875 is Teflon-impregnated white asbestos for general chemical service including potable liquids, paper pulp, gasoline and cold and hot oils and water.

Flow resistance, self lubrication, chemical inertness and a wide operating temperature range are properties claimed by E. I. du Pont de Nemours, Inc., Wilmington, Del., for its new Teflon TFE-fluorocarbon fiber developed for braided packing for pumps and valves. Removal of all carbonaceous material from fiber by bleaching and pre-shrinking (580 F for 32 hours) before braiding eliminates oxidation of carbon which causes packing to burn.

### Pipe

Glass reinforced plastic pipe and fittings for corrosion, temperature and pressure problems and tubing for structural uses such as communications towers are described in product folders available from Fibercast Company, Box 727, Sand

(Continued on Page 54)

## DeSoto Industrial Finishes

*for every maintenance requirement*

The systems listed are good reasons to call DeSoto. They are examples of the many customized finishes available for every maintenance requirement. More good reasons: You get free consultation with experienced DeSoto survey engineers.\* They'll analyze your painting problem—then recommend the best coating at the lowest possible cost.

This start-to-finish solving of industrial maintenance problems makes DeSoto your best long-range and short-term buy. Service from DeSoto is like that. Write for details.

\*PLANTS: Greensboro, N.C.

Philadelphia, Pa. • Chicago Heights, Ill. • Chicago, Ill.

Dallas, Tex. • Berkeley, Calif.



### KOROPON EPOXY COATINGS HICOR VINYL PLASTIC COATINGS

...give high corrosion and chemical resistance.

### SYNTHEX ENAMEL SYSTEMS

...protect areas where mild corrosives are prevalent.

### HEAT RESISTANT COATINGS

...withstand temperatures from 300° to 1200° F.



**De Soto** Chemical Coatings, Inc.  
1350 South Kostner Avenue, Chicago 23, Illinois





# RODINE



## acid inhibitors for safer industrial cleaning

**RODINE 213** is an organic, liquid cationic corrosion inhibitor especially designed to inhibit the attack of hydrochloric acid on copper, brass, iron and steel during industrial cleaning operations.

**RODINE** provides maximum protection to equipment during removal of metal oxides or water scale from piping systems and evaporating equipment, as well as scale and deposits from equipment in refineries, utilities, paper mills, chemical plants, other industries.

**RODINE** formulations are available to provide safer industrial cleaning in applications using virtually every form of common acids for this purpose—sulfuric, sulfamic, citric, oxalic, sodium acid sulfate, hydrofluoric, phosphoric, hydrochloric and others.

For detailed information on industrial cleaning RODINES, write for free "data package," Bulletin No. 1699.



sulfuric    sulfamic  
citric  
oxalic    phosphoric  
hydrochloric  
hydrofluoric



# RODINE



Amchem and Rodine are registered trademarks of  
**AMCHEM PRODUCTS, INC.** (Formerly American Chemical Paint Co.)  
 AMBLER, PA. • St. Joseph, Mo. • Detroit, Mich. • Niles, Calif. • Windsor, Ont.



## NEW PRODUCTS

(Continued From Page 52)

Springs, Okla. Information includes physical properties, industry applications, chemical resistance data and specifications for chemical and oil field pipe and down-hole well tubing.

High silicon iron drain pipe and fittings composing the Corrosion line marketed by Pacific Foundry and Metallurgy Company, 3100 Nineteenth Street, San Francisco, Cal., are described in 20-page catalog available from the company. Catalog itemizes dimensions and prices of over 300 items in 58 illustrated configurations.

A revised pipe friction handbook containing formulas, friction loss moduli,

friction factor charts, roughness factor charts, viscosity tables and related information has been published by the Hydraulic Institute, 122 East 42nd Street, New York 17, N. Y.

The new handbook, titled Pipe Friction Manual, is an extension and rearrangement of the institute's previous edition, "Tentative Standards of the Hydraulic Institute—Pipe Friction."

The 90-page manual is available from the institute for \$2 for domestic orders; foreign price is \$2.40.

### Plastic

A heat reactive hydrocarbon resin recommended for use in fast drying varnishes, enamels, concrete curing compounds, printing inks and adhesives is marketed as Piccodiene 2215 by Pennsylvania Industrial Chemical Corporation, Clairton, Pa. Manufacturer says

the resin is a highly aromatic polymer with unsaturated double bonds. The resin also is available in a rubber grade formulated to improve processing, heat resistance, tensile strength and resistance to abrasion.

Glass strand and resins are sprayed simultaneously on molds to fabricate fiberglass products with the Rand Fiber-Resin Depositor developed by Rand Development Corporation, 13600 Deise Avenue, Cleveland 10, Ohio. Glass-resin mass applied by this spray-up process is then rolled out by hand to remove air and to pack the mix to uniform thickness. The technique and mold designs are discussed in data sheets available from Rand.

Chemical resistance of polyester and epoxy resins in various corrosive aqueous solutions at elevated temperatures is discussed in bulletin available from Atlas Chemical Industries, Inc., Wil-

## CORROSION ENGINEERING DIRECTORY

**WAYNE BROYLES**  
CATHODIC PROTECTION  
Installation  
DESIGN SURVEYS  
**ENGINEERING CORP.**  
P.O. Box 1169 • FAirtax 3-6858 • Houston 1, Texas

**Electro Rust-Proofing Corp.**  
Engineering Division  
Corrosion Surveys  
Cathodic Protection Design  
Plans • Specifications  
Electrolysis Control  
Testing  
**ERp**  
BELLEVILLE 9, NEW JERSEY  
Atlanta • Chicago • Dallas • Monrovia

**ROSSON-RICHARDS of N.C., Inc.**  
CONSULTING ENGINEERS on  
CORROSION • COATING • WRAPPING  
SURVEYS • DESIGN • SUPERVISION  
INSPECTION • CONSTRUCTION  
DOMESTIC and FOREIGN  
P.O. Box 2053 Phone 376-0201  
**CHARLOTTE, N.C.**

**RUST PREVENTION**  
Temporary and Semi-Permanent Protection  
Indoor and Outdoor  
**HOWARD B. CARPENTER**  
CONSULTANT  
Member NACE ASME  
6 Tudor Court  
Elizabeth, N.J.

**CATHODIC PROTECTION**  
• ENGINEERING  
• SURVEYS • CONSTRUCTION  
Systems for conventional and specialized applications  
**THE HARCO CORPORATION**  
4592 East 71st St. VULcan 3-8787  
Cleveland 25, Ohio

**A.V. SMITH ENGINEERING CO.**  
Consulting Engineers  
CORROSION CONTROL STUDIES  
UNDERGROUND PIPING DESIGN  
EVALUATION AND CONSTRUCTION  
SUPERVISION  
ESSEX BLDG.  
NARBERTH, PA.

**cathodic protection service**  
**CPS**  
Twenty-five cathodic protection engineers with a combined total of over 200 years experience available to serve you with ABILITY and INTEGRITY.  
Houston 6, P. O. Box 66387  
Branch Offices: • Corpus Christi • New Orleans • Odessa • Tulsa • Pittsburgh • Los Angeles

**THE HINCHMAN CORPORATION**  
Consulting Engineers  
"WORLD-WIDE ACTIVITIES"  
Survey • Design • Supervision  
Specializing In  
**CORROSION CONTROL**  
Francis Palms Bldg. Detroit, Mich.

**SOUTH FLORIDA TEST SERVICE INCORPORATED**  
Testing—Inspection—Research—Engineers  
Consultants and specialists in corrosion, weathering and sunlight testing.  
4301 N.W. 7th St. • Miami 44, Florida

CATHODIC PROTECTION by **Coreco**  
SURVEYS • DESIGNS  
INSTALLATIONS  
**CORROSION RECTIFYING CO., INC.**  
5310 ASHBROOK • MO 7-6659  
HOUSTON 36, TEXAS

"PUTTING PERMANENCE IN PIPE"  
For Over 30 Years  
**MAYES BROTHERS, INC.**  
1150 McCarty Phone: OR 2-7586  
HOUSTON, TEXAS

**STEELE & ASSOCIATES, INC.**  
Corrosion Surveys • Cathodic Protection  
Design And Installation  
1405 Dutch Valley Place, N. E. Phone 876-9403  
ATLANTA, GEORGIA

CORROSION SERVICE LIMITED **CS** offers in CANADA  
A Complete Service in Corrosion Engineering  
Design and installation of cathodic protection systems. Supervision. Reliability and electrolysis surveys. Selection and application of protective coatings.  
17 DUNDONALD ST., TORONTO 5

**FRANCIS W. RINGER ASSOCIATES**  
• Consulting Corrosion Engineers  
135 Rolling Road MOhawk 4-2863  
CYNWYD, PA.

Reach more than 8000 paid readers monthly in this directory at a cost of about \$1.50 per thousand. Ask for rates.



ington 99, Del. Curves showing strength retention of the various resins after immersion in a number of corrosive solutions for periods to one year are included in the 16-page bulletin titled A Continuation of the Comparative Study of Corrosion Resistance of a Bisphenol A Polyester and Various Other Polyester and Epoxy Resins.

Properties and industrial applications of 13 major families are discussed in a 6-page booklet titled Getting Acquainted With Plastics available from Cadillac Plastic & Chemical Company, 15111 Second Avenue, Detroit 3, Mich. Plastics discussed include acrylic, Imlux, nylon, Teflon, polyethylene, flexible and rigid vinyl, cellulose acetate, butyrate, polystyrene, high and medium impact styrene, phenolic and fibrous glass reinforced polyesters and epoxies.

## Pumps

Air powered liquid dispensing equipment manufactured by Lincoln Engineering Company, 4010 Goodfellow Boulevard, St. Louis 20, Mo., is described in a 32-page catalog available from the company. Equipment includes pumping systems to dispense paint, cold roofing materials, food, caulking compounds and sealers, mastic adhesives and glues, vinyl material for plastic molding, inks, underbody coatings and similar fluid and semi-fluid materials. Catalog gives specifications on pumps, accessory units, measuring valves and also airless hydraulic units.

A feed pump that automatically adds desired amount of corrosion control chemicals to boilers and other water systems is marketed by Clayton Mfg. Co., Box 550, El Monte, Cal. The pump, featuring a straight through pumping member, has no pockets to trap air and cause non-uniform metering, Clayton says. Rated capacities of two models available are 1 gph at 0 to 15 psi and 0.8 gph at 15 to 100 psi.

Hermetically sealed centrifugal pumps for use with toxic, inflammable or highly volatile liquids are marketed by Buffalo Forge Company, 490 Broadway, Buffalo, N. Y. Pumps are designed for 120 psi and temperatures 40 to 250 F. For higher pressures and temperatures, special models are available. Thirteen standard models with discharge sizes of 1 to 5 inches are available.

## Safety

Safe handling and use of methyl ethyl ketone are covered in a safety data sheet, SD-83, available from the Manufacturing Chemists' Association, Inc., 1825 Connecticut Avenue, N. W., Washington 9, D. C. Price is 30 cents.

Information includes properties, hazards, engineering control of hazards, employee safety, fire fighting, handling and storage, tank and equipment cleaning and repairs, waste disposal, medical management and first aid.

Methyl ethyl ketone is a flammable liquid with a low flash point, the vapors of which form explosive mixtures with air. Although industrial use does not present a serious health hazard, undesirable effects may occur from inhalation of excessive concentrations of vapor, prolonged or repeated skin con-

tact with the liquid and from contact of the liquid with eyes, the pamphlet reports.

Safety practices for entering tanks to avoid such hazards as toxic vapors, flammable gases, lack of oxygen, electric shock and dangerous chemicals are discussed in an eight-page pamphlet costing 30 cents from the Manufacturing Chemists' Association, Inc., 1825 Connecticut Avenue, N. W., Washington 9, D. C.

## Tubing

Chemical resistant Teflon lined rubber tubing for carrying food, chemicals, petroleum products, paints, pharmaceuticals and slurries and for electrical and electronic cabling is described in a bulletin available from Pennsylvania Fluorocarbon Company, Inc., 1115 North 38th Street, Philadelphia 4, Pa. Liner is manufactured in sizes  $\frac{1}{8}$  to 1-inch ID covered with Neoprene or other elastomers in lengths to customers' specifications.

Two new plastic conduits designed for protection against corrosion and water leakage are manufactured by Consolidated Pipe Company of America, 1066 Home Avenue, Akron, Ohio. For general underground wiring, E/C conduit is available in 2 to 6-inch sizes. For general corrosion protection, PVC conduit is available in  $\frac{1}{2}$  to 6-inch sizes.

## Valves

Teflon sleeved plug valves in 8, 10 and 12-inch sizes are manufactured by Continental Manufacturing Company, 230 Park Avenue, New York 17, N. Y. Gear operated and with flanged ends, they are rated at 150 and 300 pounds for service at -50 to 400 F handling light gases to heavy slurries and corrosives. They are available in two-way or three-way bottom entry types with bodies and plugs of Alloy 20, 316 stainless steel and carbon steel with stainless steel

plugs. Ductile iron plugs are available in two-way bottom entry types.

Orifice opening is always indicated on the new Indicator Valve marketed by Flow Systems, Inc., 413 Poinsettia Street, Corona Del Mar, Cal. Also, valve operating threads are outside the valve. O-ring packing eliminates almost all interior dead space, the company says. Valve is available in either manual or air actuated style in sizes  $\frac{1}{8}$  to 4 inches with various standard tips and seats. Stainless steel, carbon steel with stainless steel trim and bronze are standard.

Phenolic molding compound for making valves to go in filter presses and for similar applications where resistance to heat and chemicals is required is manufactured by Durez Plastics Division, Hooker Chemical Corporation, North Tonawanda, N. Y. Phenolic sampling valves used in chemical filter press withstood temperatures to 195 F and a year of continuous contact with corrosive media, according to manufacturer.

A one-inch graphite globe valve is marketed by National Carbon Company, 270 Park Avenue, New York 17, N. Y. In the valve, called Type G, corrosive fluids contact only graphite and Teflon plastic, eliminating possibility of metallic contamination. Cast iron casing protects valve from mechanical damage and piping strains. Recommended maximum operating conditions are 100 psig and 338 F. Valves operate in horizontal, vertical or 45-degree positions.

Steel gate valves internally coated with a phenolic-epoxy formulation are manufactured by Edward Valves, Inc., East Chicago, Ind., which specifies valves for chemical, cement and similar process piping where abrasive-corrosive liquids and slurries are handled. Valves are available with either screwed or flanged ends in 2, 3 and 4-inch sizes. Gate, which fits into Buna-N seat insert molded to heavy steel rings, is heat

(Continued on Page 57)



Write on company letterhead for complete information, literature and recommendations.

## Prevent Weather and Salt Spray Corrosion!

**MARKAL "D-A" COATINGS**— provide metals a permanent "shield" against corrosive weather conditions, salt sprays, sulfur fumes from burning coal, water steam, hot acids, mild alkalis or other corrosive conditions at ambient temperatures up to 600°.

You can use "D-A" in a wide range of industrial applications from food and dairy plants to foundries, sawage plants and ore sintering plants, where it adheres to all metals (even galvanized without acid treatment).

Markal "D-A" is easy to use, can be brushed or sprayed.

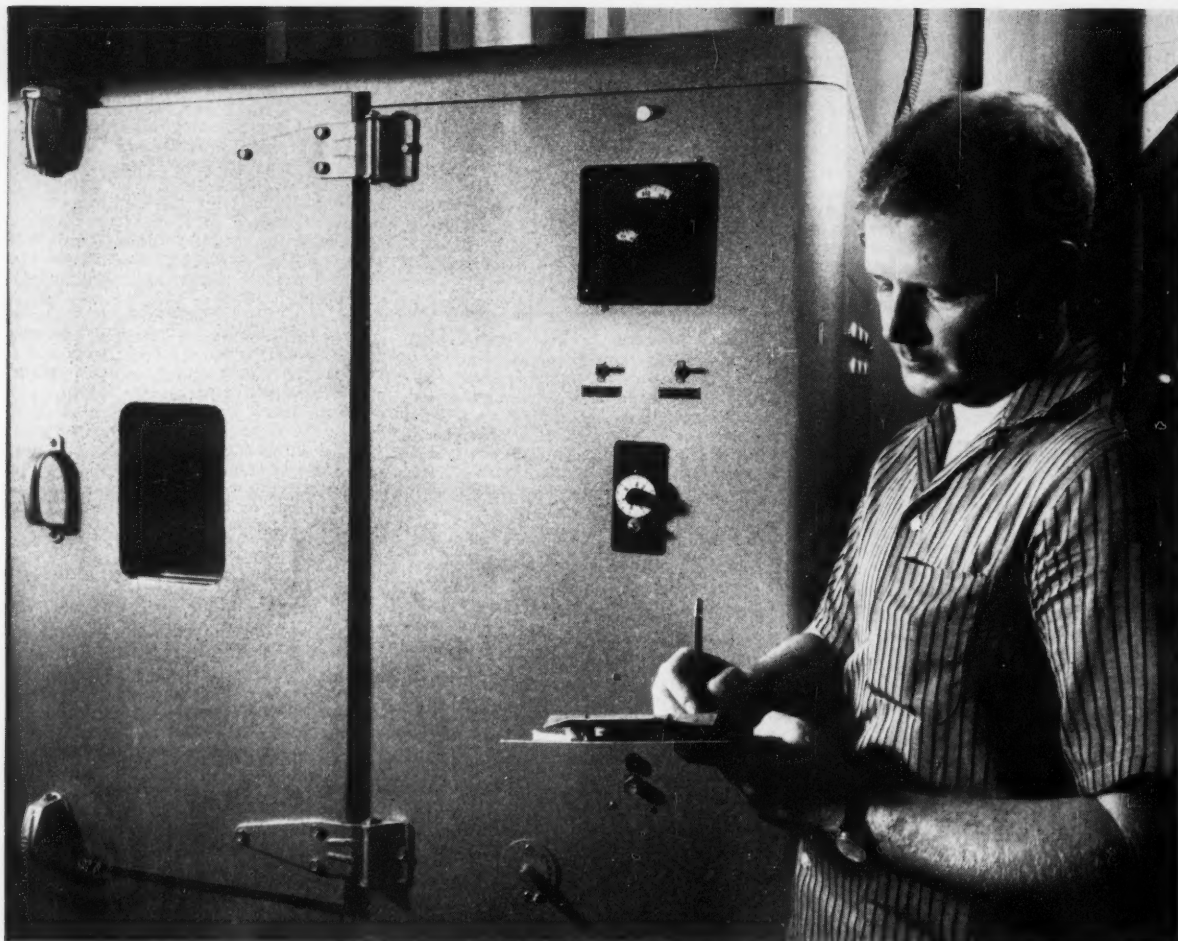
THE MARK OF QUALITY  
**MARKAL COMPANY**

3051 West Carroll Ave.

Chicago 12, Illinois

See us at the AWS Welding Show—Booth 625.





## TLC RESEARCH WORKS FOR YOU



THE PROOF OF QUALITY

New development advances in processing plastic linings for oil field tubular goods are coming from progressive TLC research. New lining techniques, new methods of quality control, new testing devices, new product formulae — all new ideas get a thorough check. Some won't work; but those that do, work better for you because of checks and counter-checks in practical application and subsequent testing.

In tests of new and established lining compounds, a pilot test oven is used to determine the exact temperatures for proper processing for field use. This is just one example of the many methods TLC uses to give research more than lip service, to make it work for you.

**TUBULAR LINING CORPORATION**

P. O. BOX 20019 • HOUSTON 25, TEXAS • JACKSON 3-7013



## MEN in the NEWS

**Thomas A. Durkee** has been appointed sales manager of Wilbur & Williams Co., Inc., 650 Pleasant St., Norwood, Mass. **Carl C. Naylor** has been named district sales manager for W&W's new central sales territory of Illinois, Wisconsin, Minnesota, North and South Dakota, Iowa, Missouri, Nebraska, Montana, Utah, Colorado and Wyoming.

NACE Member **Charles C. Nathan**, research associate at Texaco's Bellaire, Texas, Laboratories, is co-patentee of a recently issued patent covering improvements in wax removal.

Recent appointments at Shell Development Company's Research Center, Emeryville, Cal., include **J. C. Ornea**, supervisor of operations research; **John K. Uilkema**, patent, attorney, and **Miss Nancy J. Gracey**, patent searcher, in the patent division; **Robert W. Rosser**, chemist, in the organic chemistry and applications department, and **Miss Norma M. Otis**, chemical abstractor, in the technical information department.

NACE Member **Darrel D. Byerley**, field sales manager of Tinker & Rasor, San Gabriel, Cal., has been appointed general sales manager of the company's newly acquired Detectron Division.

**Charles C. Gates, Jr.**, has been named to succeed his late father as president of Gates Rubber Company, Denver, Colo.

**R. W. Ostermayer, Jr.**, has been named executive vice president of Pennsylvania Industrial Chemical Corporation, Clairton, Pa. **Albert M. Berseith** has been appointed head of process, development and maintenance.

Marketing forces have been reorganized at National Carbon Company, Division of Union Carbide Corporation, 270 Park Avenue, New York 17, N. Y. Marketing managers reporting to Director of Marketing **W. C. McCosh** are **W. W. Palmquist**, chemical and metallurgical products, **J. W. Cosby**, arc carbon products, **J. E. LeMay**, carbon products, and **M. M. Rand**, electrode and carbon refractory products. Reporting to Vice President-Marketing **C. J. Chapman** are **W. G. Pitt**, manager of new product market development, and **P. J. Hastings**, manager of nuclear and aerospace products.

**Clarence E. Larson** has been appointed a vice president of Union Carbide Nuclear Company and general manager of operations at Oak Ridge, Tennessee.

**J. O. Sandridge** has been named manager of Continental Manufacturing Company's regional sales office, 3400 Montrose Boulevard, Houston, Texas, serving the Louisiana, Texas, New Mexico and Arizona area.

**John L. Campbell** has been appointed sales manager of Stainless Foundry & Engineering, Inc., 5132 North 35th Street, Milwaukee, Wis.

NACE Member **J. Russell Wall** has been named assistant general manager of The Tapecoat Company, Evans-ton, Ill.

**W. J. McDade** has been appointed a field sales representative with headquarters in Chicago for pipeline coating by Polyken Sales Division, The Kendall Company, 309 West Jackson Boulevard, Chicago 6, Ill. His territory includes Illinois, Indiana, Ohio, Michigan, Wisconsin and Northern Kentucky.

**James A. McElroy** has been appointed general sales manager of Akron Metallic Gasket Company, Akron, Ohio.

Recent appointments at Pennsalt Chemicals Corporation, 3 Penn Center, Philadelphia 2, Pa., include the following: In the Rubber Chemicals Department, **Bryant C. Ross**, field sales manager, **Paul J. Schwert**, product sales manager, and **Daniel W. Yochum**, manager, Rubber Technical Service Laboratory. **Howard M. Brittain** has been assigned as technical service representative at Pennsalt's Atlanta Regional Office, College Park Road, Hapeville, Ga.

NACE Member **William H. Aretz** has been named to head pipe wrapping activities of Ralph V. Rulon, Inc., Philadelphia 40, Pa.

**Loy C. Collingwood** has been appointed manager of Alloy Metal Wire Works, one of three plants of Riverside-Alloy Metal Division, H. K. Porter Company, Inc., Riverside, N. J.

**G. Robert Couch** has been appointed technical advisor to the vice president—Eastern operations of Climax Molybdenum Company, Division of American Metal Climax, Inc., 1270 Avenue of the Americas, New York 20, N. Y.

In the chemical division of Pittsburgh Plate Glass Company, One Gateway Center, Pittsburgh 22, Pa., **Paul A. Fodor, Jr.**, has been appointed director of sales and **O. W. Andrews** director, marketing services. In the paint and brush division research and development center at Springdale, Pa., **Henry A. Vogel** has been appointed manager, consumer products development, **Pierson G. Boermans** manager, trade sales technical service, and **Robert P. Ericson**, manager, industrial coatings development.

NACE Member **E. Dale Barcus**, toll service transmission engineer for Pacific Telephone and Telegraph Company, Los Angeles, Cal., has been named a fellow of the American Institute of Electrical Engineers.

**George A. Reilly** has joined Reilly Tar & Chemical Corporation, Indianapolis, Ind., as vice president and general counsel. In addition he has been appointed general manager of Republic Creosoting Company, a division of Reilly Tar.

**Charles M. Herzfeld** and **William A. Wildhack** have been appointed associate directors of the National Bureau of Standards, U. S. Department of Commerce, Washington, D. C.

NACE Member **John L. Eberly**, president of Eberly Dynamics Inc., has announced the purchase of Protective Plastic Company, 5116 Richmond Road, Bedford, Ohio.

**Earl Henry Lenz** of Buffalo Forge Company, Buffalo, N. Y., and **Ralph David Barer**, consulting engineer, Victoria, B. C., Canada, have been awarded \$1000

prizes by American Hot Dip Galvanizers Association for achievements in research, development and utilization of hot dip galvanized products.

Dow Chemical Company, Midland, Mich., has announced the appointment of **Earle B. Barnes** of Freeport, Texas, as an assistant secretary, succeeding **Luther Evans**. Barnes is general manager of Dow's Texas Division. Evans, formerly assistant general manager of the Texas Division, has been named manager of the Rocky Flats, Colo., plant which Dow operates for the U. S. Atomic Energy Commission.

**Chester G. Borlet** has been appointed plating products specialist for the Plating Division of Metal & Thermit Corporation. His offices are at 1700 East Nine Mile Road, Detroit 20, Mich.

**Jack Gray** is president and general manager of the newly organized protective coating concern of Omega Engineering, Inc., Odessa, Texas.

## NEW PRODUCTS

(Continued From Page 55)

treated chromium-molybdenum steel plated with chrome. Maximum temperature for Buna-N insert is 250 F.

### Welding

Arc welding equipment featuring small diameter electrode wire and employing carbon dioxide or gas mixtures is marketed by National Cylinder Gas Division, Chemetron Corporation, 840 North Michigan Avenue, Chicago 11, Ill. The semi-automatic MiniArc equipment welds light gage metals in any position, Chemetron says. Equipment consists of an AM-8 torch, WC-5 control with wire drive, interconnecting gas and flexible conduit assemblies. Wire feed rate is 55 to 500 inches per minute. Wire sizes are .025, .030 and .035 inches. Size is 12¼ x 16 x 20 inches.

An electric welding kit to repair thermoplastic products is marketed by Kamweld Products Company, 932 R Washington Street, Norwood, Mass., which says the kit also is useful for training welders. Equipment is suitable for tack welding, hand welding and medium speed welding of such thermoplastics as polypropylene and polyethylene, rigid and plasticized PVC and also plasticized tank linings, Kamweld says. Kit contains a welder, aluminum stand, round welding tip, tack welding tip, a 16-foot neoprene air hose, practice pieces and instruction manual.

An electric welder for most thermoplastics, including plasticized vinyl tank linings, unplasticized rigid polyvinyl chloride, polyethylene and polypropylene is available from Seelye Plastic-Fab, Inc., 984 Central Avenue, Minneapolis 13, Minn. It can be used to produce butt, lap and curved welds and others with speeds averaging 48 inches per minute on simple flat or curved surfaces. Hot nitrogen or compressed air heats both area being welded and welding rod which is fed automatically through tip. Welder is 14 inches long, weighs 14 ounces and operates on 100 v AC.



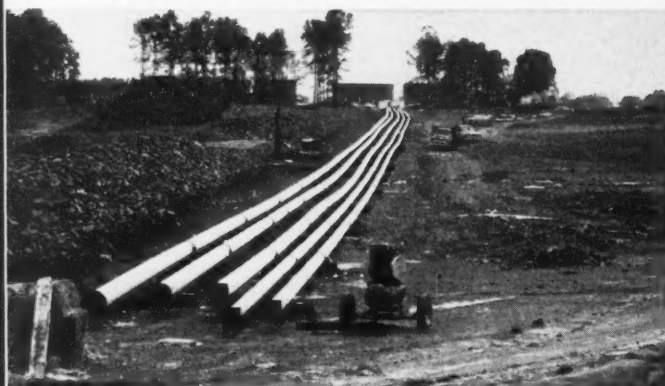


▲ **NATURAL GAS** lines at compressor and meter stations give years of maintenance-free service when protected by TAPECOAT, the coal tar coating in handy tape form.

▲ **GAS DISTRIBUTION** lines of large diameter can readily be protected with TAPECOAT to withstand the abrasive and corrosive climate in underground service.



▲ **CABLE AND CABLE SPLICES** in communications service are effectively and economically protected by TAPECOAT.



▲ **AIRPORT FUEL LINES** need the quality joint protection assured by TAPECOAT. It is easy to apply by spiral or "cigarette" wrapping depending on the size of the pipe. No training needed.

▲ **STEEL MILL** water lines in this new plant are joint-protected with TAPECOAT. TAPECOAT can be used to advantage to protect any steel surface in underground service, as proved since 1941.



▲ Lines in **OFF-SHORE DRILLING** operations need joint protection equivalent to the mill-wrapping on the pipe. TAPECOAT is most economical because it gives lasting protection in underwater service.



▲ **UNDERGROUND GAS STORAGE** facilities can be "buried and forgotten" when protected by TAPECOAT. Note protection of tanks, pipe and pipe joints.

▲ Lines buried in cinders in **RAILROAD YARDS** need the sure protection provided by TAPECOAT. There's a size for every purpose from 2" to 24" in width.



Write for full details today

*The* **TAPECOAT**  
*Company*

Originators of Coal Tar Coating in Tape Form

1529 Lyons Street, Evanston, Ill.

Manufactured and Distributed in Canada by  
The Tapecoat Company of Canada, Ltd.,  
25 Haas Road, Rexdale, Ontario.







## NACE NEWS

# 43 Firms Hold Booths for 1962 Corrosion Show

## Reserve 50 Percent Of Exhibition Space At Kansas City Show

So far, 43 companies have reserved booths for the 1962 Corrosion Show in Kansas City, Missouri, March 20-22. These companies, holding 50 percent of the exhibition space, are listed below, their products in the accompanying box.

This year's show, shaping into a good cross section of corrosion controls available, will be staged in the Exhibition Hall of the downtown Municipal Auditorium. A block away is Hotel Muehlebach, headquarters for the 18th Annual NACE Conference which starts a day before and ends a day later than the show. To avoid creating any confusion, here is a preview of conference arrangements: On the first day of the conference, March 19, the technical program will be held in Hotel Muehlebach. The next day and thereafter, the program will be presented in the Municipal Au-

ditorium's 4th, 5th and 6th floor conference rooms and the Little Theatre on the ground floor.

As at past shows, the exhibits will be photographed and incorporated into slide shows for distribution to NACE sections as program material.

Companies desiring to exhibit at the show should contact R. W. Huff, Jr., NACE Exhibits Manager, 1061 M & M Building, Houston 2, Texas.

### Companies Holding Space

Aluminum Company of America  
Amercoat Corporation  
American-Marietta Company  
American Smelting and Refining Company  
Black, Sivalls & Bryson, Inc.  
California Chemical Company,  
Oronite Division  
Carboline Company  
Carpenter Steel Company,  
Alloy Tube Division  
Cathodic Protection Service  
Centriline Corporation  
Clementina Ltd.  
Columbus Coated Fabrics Company  
Cook Paint & Varnish Company  
Detroit Graphite Company

Dow Chemical Company  
Duriron Company, Inc.  
Encyclopaedia Britannica  
Flower Company, Arch T.  
Glidden Company  
Harco Corporation  
Hercules Powder Company  
Hills-McCanna Company  
International Nickel Company, Inc.  
Johns-Manville  
Kendall Company, Polyken  
Sales Division  
Koppers Company, Inc.,  
Tar Products Division  
Lincoln Engineering Company  
Marwais Manufacturing Division,  
Marwais Steel Company  
National Carbon Company  
Pittsburgh Corning Corporation  
Price Company, H. C.  
Reilly Tar and Chemical Corporation  
Republic Steel Corporation  
Resistoflex Corporation  
Royston Laboratories, Inc.  
Shell Chemical Company  
Standard Magnesium Corporation  
Steele & Associates, Inc.  
Socony Paint Products Company  
St. Louis Metallizing Company  
Tinker & Rasor  
Truscon Laboratories  
Wheelabrator Corporation

### Products Set for National Show

Aluminum  
ANODES  
Graphite  
Impressed current  
Magnesium  
Backfill, coke breeze  
Blast cleaning equipment  
CATHODIC PROTECTION  
Anodes  
Backfill  
Engineering services  
Equipment and materials  
Generators, thermoelectric  
Rectifiers  
Cements  
COATINGS  
Application equipment  
Ceramic  
Metallic  
Plastic  
Generators  
INSTRUMENTS  
Cathodic protection  
Flaw detectors  
Pipe finders  
Insulation, pipe  
Laminates, vinyl-metal  
LININGS  
Cement-mortar  
Epoxy-resin  
Pipe  
Sheet  
Tank  
Magnesium ribbon

Metals  
Molding powder  
Nickel  
Nickel alloys  
PIPE  
Fittings  
Insulation  
Plastic  
Plastic lined  
Seals  
Stainless steel  
Tapes  
PLASTICS  
Molding powder, chlorinated polyether  
Pipe  
Pipe, lined  
Resins, polyester  
Tanks, filament wound  
Tape  
Pumps  
Raceways, electrical  
Rectifiers  
Reference books  
Ribbon, magnesium  
Sandblasting equipment  
Seals, pipe  
Stainless steel pipe  
Surface preparation equipment  
TANKS  
Filament wound  
Linings  
Tapes, pipe  
Tubing  
Valves

### South Central Region

## 131 From 13 States Attend Oklahoma Short Course

Attendance at the Eighth Annual Oklahoma Short Course September 27-29 was 131. Thirteen states, including Hawaii, and Canada were represented.

More than half the registrants had not attended the course before and of this group most were new to the field of corrosion control, Chairman R. D. Daniels says.

The 1962 course is scheduled September 26-28 at the University of Oklahoma campus in Norman. It is sponsored each year by the university's College of Engineering and Extension Division in cooperation with the Central Oklahoma Section of NACE.

### Conference Cities Approved for 1962-66

Cities for South Central Region conferences for the years 1962-66 have been approved by the Board of Trustees. They are as follows:

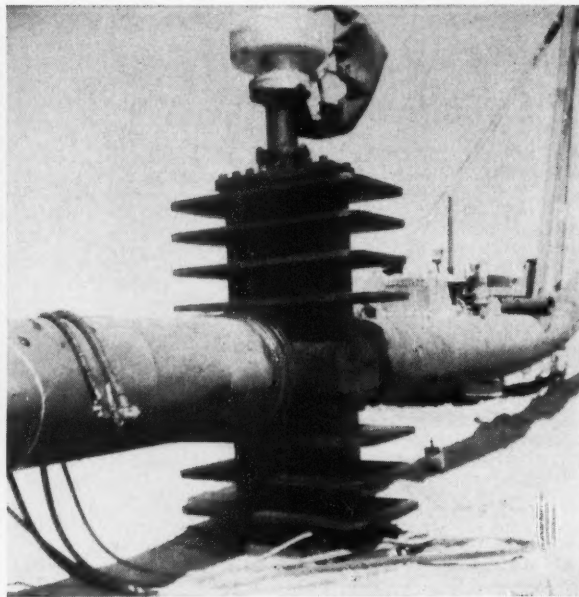
1962—San Antonio—October 16-19  
1963—Oklahoma City—October 14-17  
1964—Dallas—Undetermined  
1965—New Orleans—October 12-15  
1966—Denver—Undetermined  
(Continued on Page 61)



# EL PASO NATURAL GAS COMPANY PROTECTS LINE VALVES WITH ROSKOTE COLD-APPLIED MASTIC



Roskote cold-applied mastic was spray-applied to 30" valves by El Paso Natural's personnel at Grants, New Mexico. Risers and support legs were coated with Roskote and wrapped with Royston Glas-Wrap for additional mechanical abrasion protection.



On the El Paso Natural Gas Company line being laid at Fort Stockton, Texas, by Western Pipeline Company, all 20" valves were spray-coated with Roskote cold-applied mastic.

You get superior protection against the most severe field corrosive agents with Roskote cold-applied mastic. Valves, risers, line pipe, tanks and other structures above or below ground are coated with Roskote by spray or brush without heat, flame or toxic and irritating effect on workers. The quick-drying feature of these mastics permits early backfilling. Roskote's time-saving, cost-saving application complements its low first cost to provide you with the most economical means of long-life metal protection.

Roskote is applied cold winter or summer. It retains its plasticity at 0°F, and will not run or sag at 250°F. Its high dielectric strength and resistivity, and its superior resistance to acids and alkalis provides ample protection even under the most rigorous underground or atmospheric corrosive conditions. Specific formulations are available for resistance to high crude oil concentrations and gasoline seepage in surrounding soil.

Royston engineers will give prompt attention to your inquiry.

## ROYSTON LABORATORIES, Inc., P.O. BOX 112-C, PITTSBURGH 38, PA.

### District Sales Offices:

P.O. Box 1084  
Atlanta, Georgia

P.O. Box 1753  
Tulsa, Oklahoma

P.O. Box 8188  
Houston 4, Texas

1605 Ventura St.  
Midland, Texas

3114 Midvale Avenue  
Philadelphia 29, Pa.

Overton Sales Equipment Co.  
5981 Fairmount Extension  
San Diego 20, Calif.



5225 Clover Drive  
Lisle, Illinois  
(Chicago District)



## South Central Region

(Continued from Page 59)

**Central Oklahoma** heard Ted Canfield of Cathodic Protection Service, Tulsa, discuss two films he presented at the meeting on October 2. One film was on magnesium anodes, the other on cathodic protection with impressed currents. An unexpected guest at the meeting was Senator Mike Monroney who was attending a Kiwanis meeting across the hall. Having dropped in to say hello, he stayed to comment on aircraft corrosion.

B. O. Stampely of Aquaness, Oklahoma City, will be guest speaker at the section's November 6 meeting.

**Teche Section** heard Otto L. Grosz of the California Company, New Orleans, present a summary of corrosion control of a typical offshore structure October 4.

**Tulsa Section** heard John R. Weinert of Pittsburgh Chemical Company, Pittsburgh, discuss general theories of corrosion and its prevention by protective coatings September 25.

**Shreveport Section** heard Floyd B. Thorn of Cathodic Protection Service, Houston, discuss thermoelectric generators for cathodic protection October 3. Thirty-one attended.

**East Texas Section** met in Longview September 26 to hear M. J. Olive of Corrosion Control Associates discuss cathodic protection and its role in the East Texas oil field.

## DEATHS

**Orvis A. Melvin**, chairman of the Houston Section and sales engineer for the Carboline Company, died Saturday, October 14, in a Houston hospital following an operation.



Melvin

An enthusiastic worker in the Houston Section since joining NACE in 1954, he had served as secretary - treasurer and vice chairman of the section and on the entertainment and other committees. He also had been active in the Houston Coating Society.

Before joining Carboline in 1955, he was associated with Vaport Honing Company, Inc.

Mr. Melvin, a resident of Houston for the past 40 years and a member of Saint Patrick's Episcopal Church, is survived by his wife, Mrs. Florine Melvin, and three sons, Orvis Melvin, Jr., Michael and Patrick Melvin.

## Canadian Region

**Edmonton Section** heard J. V. Hayward of Dominion Bridge Co. discuss non-destructive testing systems for welded fabrication August 24.

## Southeast Region

### Ladies' Program Starts With Coffee

A coffee on the patio of the Key Biscayne Hotel at 9:30 a.m., Tuesday, November 28, starts the ladies' program at the Southeast Region's Miami conference. At the coffee, the entertainment committee will brief the ladies as to activities planned for them.

The ladies, naturally, are invited to the luau, social hour, banquet and dance.

And, naturally, sunshine awaits all at Miami where golden suntans are yours for the basking. Recreational facilities of the Key Biscayne Hotel include a private, 1100-foot beach, two swimming pools, a nine-hole pitch 'n putt golf course and tennis courts.

### Miami Conference Registration Begins at 9 a.m., Nov. 27

Registration at the Southeast Region Conference in Miami begins at 9 a.m., November 27, in the main lobby of the Key Biscayne Hotel. The technical program, which appears on Page 68 of October CORROSION, starts at 1:30 that afternoon in the hotel's Santa Marta Room just off the main lobby.

The registration fee is \$12; it includes a ticket for the Luau and the Social Hour. Banquet tickets are \$5. No registration fee is required for wives of registrants; however, additional tickets for the Luau or Banquet will be \$5.

### PROGRAM SCHEDULED FOR MIAMI CONFERENCE

#### Monday—November 27

9:00 - 12:00 Registration—Main Lobby  
1:30 - 5:00 Technical Program—Santa Marta Room

#### Tuesday—November 28

9:30 Ladies' Coffee—Patio  
9:30 - 5:00 Technical Program—Santa Marta Room  
5:30 S.E. Region Nominating Committee—Key Cove Room  
7:00 Luau—El Bohio

#### Wednesday—November 29

9:00 - 12:00 Technical Program—Santa Marta Room  
1:30 NACE Board Groups—Key Cove Room  
1:30 S.E. Region Board of Trustees—Santa Marta Room  
1:30 - 5:00 Visit to Displays—Lower Lobby

#### Thursday—November 30

9:00 - 5:00 NACE Board of Directors—Key Cove Room  
9:00 - 5:00 Technical Program—Santa Marta Room  
12:30 S.E. Region Business Luncheon—Island Room  
7:00 - 8:00 Fellowship Hour—Island Room  
8:00 Banquet and Dance—Dining Room

#### Friday—December 1

9:30 - 12:00 Technical Program—Santa Marta Room

### Ohio Valley Elects Section Officers

The Ohio Valley Section of the Southeast Region has announced the election of the following officers:

Chairman C. N. Beck of Louisville Gas & Electric Company, Vice Chairman John S. Heintzman of Southern Bell Telephone & Telegraph Company and Secretary-Treasurer Robert L. Whitehouse of Irvin H. Whitehouse & Sons Co.

Steel ingot production in the United States in 1960 was 99.3 million tons, a 6 percent gain over 1959 production.

## COKE BREEZE

### Backfill for Anodes

Ideally suited for use with anodes. Has a high carbon content and comes in sizes of 1/4-inch x 0 to 1/2 x 1/2 inch. In bulk or sacks. Prices on other sizes on request.

Special DEEP WELL  
Fine Coke Backfill—100 Mesh  
National Carbon Anodes  
Magnesium Anodes

## WHOLESALE COKE COMPANY

PHONE GARDENDALE, ALA.  
HEmlock 6-3603

P.O. Box 94

Mt. Olive, Ala.





On sales to Texas addresses add 2% tax.

248 pages, 8½ x 11 inches, plastic back, flat opening.

Contains complete NACE Abstract Filing System Index, 2136 abstracts of 1956 corrosion control literature alphabetical list of 2859 authors, thorough alphabetical subject index, complete cross-references.

This book gives you an easily used key to the published data on corrosion control during 1956. Use it to save countless hours of time searching general indexes; take advantage of this wealth of carefully classified information in solving your corrosion problems. The book has been rearranged for quicker reference, easier use. Order your copy today.

# 1956 Bibliographic Survey of Corrosion

**Topically Arranged  
Topically Cross-Indexed  
Alphabetically Indexed  
Author Index**

NACE Members  
**\$22.50**

Non-Members  
**\$27.50**

• Foreign remittance should be by international postal or express money order or bank draft negotiable in the U. S. for an equivalent amount of U. S. funds.

• In addition to the prices shown above, there is a charge of 65c per package for registered book post to addresses outside the U. S., Canada and Mexico.

## *Get the Keys to 11 Years of Corrosion Control Literature*

These six volumes cover the 11-year period 1945-55 in 20,045 abstracts carefully classified by the NACE Abstract Filing System. Every volume cross-indexed, with alphabetical subject and author indexes. Save valuable research time with these abstracts.

**BUY ALL SIX  
VOLUMES**

**\$40**

Note cost of Book Post  
Registry

1954-55 VOLUME,  
containing 4287 ab-  
stracts  
NACE  
Members..\$15  
Non-  
Members..\$20

1952-53 VOLUME,  
containing 3344 ab-  
stracts  
NACE  
Members..\$10  
Non-  
Members..\$12.50

1950-51 VOLUME,  
containing 4454 ab-  
stracts  
NACE  
Members..\$10  
Non-  
Members..\$12.50

1948-49 VOLUME,  
containing 3512 ab-  
stracts  
NACE  
Members..\$10  
Non-  
Members..\$12.50

1946-47 VOLUME,  
containing 3362 ab-  
stracts  
NACE  
Members..\$ 7  
Non-  
Members..\$ 9

1945 VOLUME,  
containing 1086 ab-  
stracts  
NACE  
Members..\$ 4  
Non-  
Members..\$ 5

(This book not indexed by  
the NACE Abstract Filing  
System)

Remittances should include 75¢ for book post registry of single volumes; or, for all six volumes, \$1.95 to all addresses outside of the United States, Canada and Mexico. Foreign remittances should be by international postal or express money order or bank draft negotiable in the U. S. for an equivalent amount in U. S. funds.

Send Orders and Remittances to

**NATIONAL ASSOCIATION of CORROSION ENGINEERS**

1061 M & M Bldg.

T. J. Hull, Executive Secretary

Houston 2, Texas





Nov. 27-Dec. 1—Southeast Region Conference and Florida General Conference Short Course, Key Biscayne Hotel, Miami, Fla.

Nov. 29-30—NACE Board of Directors Meeting, Key Biscayne Hotel, Miami, Fla.

#### 1962

January 17-19—Canadian Region Eastern Division Conference, King Edward Hotel, Toronto, Ontario.

March 18—NACE Board of Directors Meeting, Muehlebach Hotel, Kansas City, Mo.

March 19-23—18th Annual Conference and 1962 Corrosion Show, Kansas City, Missouri, Municipal Auditorium.

March 23—NACE Board of Directors Meeting, Muehlebach Hotel, Kansas City, Mo.

October 1-4—Northeast Region Conference, Hotel Sheraton Ten Eyck, Albany, N. Y.

October 9-11—North Central Region Conference.

October 11-12—Southeast Region Conference, Birmingham, Ala.

October 16-19—South Central Region Conference and Exhibition, Granada Hotel, San Antonio.

#### 1963

March 18-22—19th Annual Conference and 1963 Corrosion Show, Convention Hall, Atlantic City, N. J.

October 14-17—South Central Region Conference, Oklahoma City, Okla.

October 22-24—Northeast Region Conference, Niagara Falls, N. Y.

#### 1964

March 9-13—20th Annual Conference and 1964 Corrosion Show, Sherman Hotel, Chicago, Ill.

October 25-30—North Central Region Conference, Hotel Lemington, Minneapolis, Minn.

#### 1965

March 15-20—21st Annual Conference and 1965 Corrosion Show, Chase-Park Plaza Hotel, St. Louis, Mo.

### SHORT COURSES

#### 1962

Feb. 21-23—12th Annual Corrosion Short Course, Tulsa, Okla.

Sept. 26-28—9th Annual Central Oklahoma and University of Oklahoma Corrosion Control Short Course, Norman.

## North Central Region

### T-5D Working on Numbering System For Plastics

Technical Committee T-5D, Plastic Materials of Construction, meeting in St. Louis October 9 in conjunction with the North Central Conference, resumed its work toward establishment of a numbering system for structural plastics for corrosion control.

Plans made by the committee to progress the project include (1) presenting the committee's aim to establish such a numbering system to fabricators attending a meeting of the Society of the Plastics Industry in November and (2) establishing liaison with the Manufacturing Chemists Association which is working on standards for plastic materials of construction.

Cleveland Section scheduled a tour of Norton Salt Company, Painesville, Ohio, October 17.

Anton de S. Brasunas of American Society for Metals spoke on corrodibility September 19.

Twin Cities Section will hear Clifford J. Ulheimer of Mobil Oil Company, Paulsboro, N. J., discuss organic corrosion inhibitors for lubricating oils November 14.

Kansas City Section scheduled D. R. Baker of Marley Company, Kansas City, Mo., to speak on deterioration of cooling tower materials October 9.

Two movies titled Cathodic Protection With Galvanic Anodes and Cathodic Protection With Impressed Current were shown at the September meeting. T. Canfield of Cathodic Protection Service was on hand to answer any questions regarding the movies.

Southwestern Ohio Section heard Donald B. Jones of Goodyear Atomic Corporation speak on corrosion of cooling water systems September 26. William Eckert gave an illustrated talk on the 1961 NACE annual conference in Buffalo.

## Western Region

Portland Section heard Israel Cornet of the University of California speak on current research on corrosion fatigue and velocity effects September 7. Attendance was 46.

San Francisco Bay Area heard John C. Wood of Garratt-Callahan Company discuss unusual corrosion problems experienced in boiler systems and water cooling systems September 12. In attendance were 25 members and 26 guests.

Steel manufacturers in the United States during the past five years produced annually 1,162 lbs of steel per American.

## Northeast Region

Pittsburgh Section heard Charles J. Code of the Pennsylvania Railroad Company discuss corrosion problems in connection with railroad tracks on October 12. Approximately 40 people attended.

For November 2, the section scheduled G. F. Bush of Ford Motor Company to speak on corrosion of exterior automotive trim. A round table on underground corrosion will be held December 7; Chairman will be C. A. Erickson of Peoples Natural Gas Company.

Kanawha Valley Section heard John Lomax of Hercules Power Company speak on field experiences with corrosion resistant Penton coatings and linings September 21 at Huntington, W. Va. Attendance was 21. Two professors and one student from Marshall University attended as guests of the section as part of the program under way to bring corrosion and materials engineering to the attention of local students.

At this meeting, F. A. Radford of Godfrey L. Cabot Company, Charleston, W. Va., was elected treasurer to replace James Parker who has been called to active military duty.

Twenty-six percent of the estimated 1960 world steel output was produced in the United States.

## Corrosion Testing Coupons, Spool Parts

STANDARD SIZES

OR

Made To Your Specifications



Over 70 Materials in Stock  
For Quick Delivery  
Write us for your Testing needs.

**CORROSION  
Test Supplies Co.**

P. O. Box 176

Baker, La.

We Ship Anywhere in the World



## Overseas Correspondents

### CEBELCOR Is Major Corrosion Group In Belgium

In Belgium, corrosion receives the attention of several special organizations and numerous industrial laboratories.

The greatest amount of corrosion work is done by Centre Belge d'Etude de la Corrosion (CEBELCOR) which includes fundamental research as well as specific practical problems.

In the fundamental field a potentiodynamic method of studying electrochemical surface phenomena has been developed. This has been applied to the behavior of steel and steel alloyed with copper in various media, to aluminum and to copper with a view of determining how a passivating film is formed and the role of chloride. These studies have led to the establishment of equilibrium diagrams (corrosion, passivity and immunity) for binary and ternary systems and to the improvement of electronic potentiostatic apparatus. An atlas of electrochemical equilibria will soon be published in both French and English.

Together with Centre d'Etudes Nucleaires (CEN) and the S.E.R.A.I., CEBELCOR is working on a large program for EURATOM. The aim of this project is to determine how the electrochemical behavior of metals can be used to predict their corrosion behavior in nuclear energy plants.

Using potentiostatic methods, intensive work has been carried out on the behavior of stainless steel in dilute sulphuric acid solution and in chloride solution. Aluminum also has been investigated.

Applied research has included a study of the corrosion of steel reinforcing bars in concrete as well as specific cases of corrosion such as boilers, anodized aluminum, water pipes, heat exchangers, water coolers, performance of different chromium steels, etc.

Another important activity of CEBELCOR has been the publication of

technical reports and the presentation of lectures on corrosion research and prevention.

Much corrosion work is also done by Centre Belge d'Etude et de Documentation des Eaux (CEBEDEAU) whose main concern is the corrosion of steel products by water. Studies have been made also in the field of season corrosion in the sugar industry.

Centre National de Recherches Metallurgiques (CRNM) is carrying on a test program on the atmospheric corrosion of structural steels.

A study of the performance of different paint systems started a few years ago by ABEM IV is continuing.

In the last two cases samples are being tested in industrial and marine areas of Belgium.

Y. Lannoye  
R. Crunelle

Centre Belge d'Etude de la Corrosion  
24 Rue des Chevaliers  
Bruxelles 5  
Belgium

### 9 Groups Active In Corrosion Work in Israel in 1960

In Israel, major corrosion control activities during 1960 were carried on by the following organizations:

1. The Corrosion Group—Associates of Engineers and Architects. Various corrosion topics were discussed by Corrosion Group members at several lectures. A number of lectures from abroad participated in these meetings, their opinions arousing great interest.

2. Technion—Israel Institute of Technology. A corrosion research laboratory was established at the Technion as part of the Israel Metals Institute. Further progress has been made in research of concrete corrosion at the Building Research Station. This research includes bonding of reinforced concrete elements in connection with corrosion danger to reinforcement and the influence of cracks in reinforced concrete structures on the corrosion of reinforcement in different climatic zones, temperature on corrosion of reinforcement and climate on corrosion of concrete reinforcement.

3. Water Planning for Israel, Ltd. Various cathodic protection projects were planned and carried out. A major project of cathodic protection of 140 miles of oil pipelines, designed and installed by D. Spector as contractor, was completed.

Several experts from France and the United States were invited by the above organization to deal with problems of corrosion of prestressed reinforced concrete water mains.

4. Water Department—Jewish Agency, Ltd. Irrigation systems in several villages were cathodically protected.

5. ZIM—Israel Navigation Company. New tankers, recently launched, were cathodically protected according to design of Spector Cathodic Protection,

Ltd. First steps toward hull protection were taken.

6. Israel Electricity Company. Cathodic protection of a long crude oil sea outlet.

7. Municipality of Tel Aviv. Planning and design of cathodic protection of prestressed reinforced concrete water mains by D. Spector consultants. Groundbed installations 300 feet deep were made for the first time in this country.

8. Post Ministry. Survey and design of cathodic protection of interurban trunk cables 180 miles long.

9. D. Spector—Corrosion Engineers. Acted as consultants on corrosion problems to most of the above organizations and design and installation of various cathodic protection projects all over the country.

D. Spector  
22 Harakevet Street  
Tel Aviv, Israel



## SECTION CALENDAR

### November

- 1 Teche Section
- 2 West Kansas Section
- 2 Pittsburgh Section, Corrosion of Exterior Automotive Trim by G. F. Bush of Ford Motor Company
- 6 Central Oklahoma Section
- 14 Houston Section, Student Night, Hydraulic Spray Application of Fiberglass Reinforced Epoxy and Polyester Resins by Moody Adams of Matcote.
- 14 Twin Cities Section, Organic Corrosion Inhibitors for Lubricating Oils by Clifford J. Ulheimer of Mobil Oil Company
- 15 Wilmington Section, Protective Coating by James E. Parkinson of U. S. Navy Yard.
- 16 Vancouver Section, Boiler Corrosion and Metallurgical Aspects of Boiler Tube Failures by R. D. Barer of Pacific Naval Laboratory.
- 21 Alamo Section
- 21 Chicago Section, Half a Century of Research in Glass by J. W. McClellan of Corning Glass Works
- 27 New Orleans Section

### December

- 1 Appalachian Underground Corrosion Short Course General Committee meeting in Pittsburgh, Pa.
- 4 Central Oklahoma Section
- 6 Teche Section
- 7 West Kansas Section
- 7 Pittsburgh Section, Underground Corrosion Round Table, Chairman C. A. Erickson of Peoples Natural Gas Company
- 8 Rocky Mountain Section
- 12 Twin Cities Section
- 12 Houston Section, Chemical Industry Development in Texas and Educational Trends in Engineering Schools by J. D. Lindsay of Texas A&M College. Ladies Night.
- 19 Alamo Section
- 19 Philadelphia Section, Management's Concern With Corrosion by G. E. Best

**Make SEA WATER**

**-ANYWHERE!**

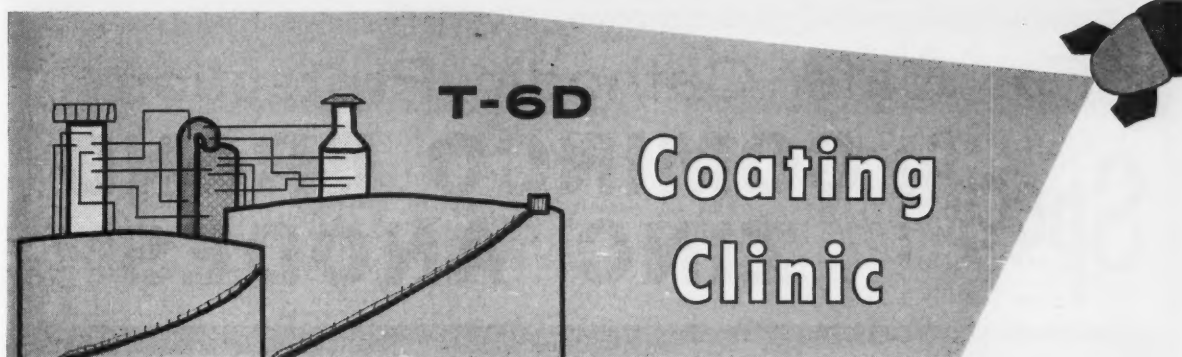
**SEA RITE SALT**

for CORROSION STUDIES

4½ oz. Sea Rite Salt crystals in one gallon tap water produces laboratory sea water quickly, inexpensively. Provides uniform, constant results based on 77 composite analysis. Immediate delivery — any quantity. Technical literature on request. Write, wire, phone now!

**LAKE PRODUCTS CO., Inc.**  
ST. LOUIS 25, MISSOURI





If you have a question or problem related to industrial paint applications, NACE Technical Unit Committee T-6D will forward it to qualified men in the industrial coating field for answers and suggested solution to problems. State your problem fully. Questions should be addressed to T-6D Coating Clinic, Corrosion Magazine, 1061 M & M Bldg., Houston 2, Texas.

### Water Blasting

The question on water blasting on Page 71 of the September issue stimulated considerable interest. At present, the only equipment source known is the E. L. Lester Company, 5050 Holmes Road, Houston 33, Texas. Additional information on this surface preparation method and availability of equipment would be appreciated.

### Bubbles in Sprayed Paint Films

**What are the causes of small bubbles in fresh paint films applied by air and airless spray?**

There are probably as many different causes as there are bubbles; however, here are a few of the causes:

#### Air Spray:

1. To high fluid pressure and/or too low atomizing air pressure. Air becomes entrained in the fluid and breaks out after reaching the surface being coated. This can be corrected by proper adjustment of equipment.

2. Steel that has been over-pickled will develop a porous, spongy surface which will create bubbles as the contained air is displaced by the coating. This, obviously, can be corrected by proper pickling.

#### Airless Spray:

1. Improper solvent balance or pigmentation. This can be corrected by reformulation.

2. Too low or too high viscosity. This can be corrected by thin coating to proper viscosity.

### Equipment Height Versus Coating Failure

**Why do paint or coating films applied to the exterior of petroleum products tanks almost always display their first failure at the top two or three rings of the tank? (This is a repeated question. See Page 71 of the September issue for another possible answer.)**

Assuming that most painting has been done by the air spray method, the fluid flow (as adjusted on the ground for proper atomization with air atomized

equipment) drops while the atomizing air pressure remains constant, thereby resulting in an overly dry spray which is no longer free flowing. The resulting film is more porous and consequently permeated more easily by moisture, thus giving premature failure.

Corrective measures would include adjustment of equipment at application height or keeping the pressure pot at the coating level.

Comments from readers suggest several other possible causes of this failure phenomenon:

1. One suggests that the degree of supervision and quality of inspection is inversely proportional to the height and inconvenience of the object being painted; therefore, the durability of the film suffers to the same degree. Corrective measures suggested are agile supervisors and inspectors and more conscientious painters.

2. Another reader suggests that the velocity of the wind increases from the bottom to the top of tanks, frequently making it more difficult to deliver overspray-free films to the surface. Corrective measures for this cause would include (a) job planning, (b) adjustment of air spray equipment to deliver proper films six to eight inches from the surface, and (c) the possible use of airless spray equipment if the product being applied is adaptable to that method.

Additional suggestions on answering this question are welcomed. Submit such suggestions to the address given above. Apparently, this problem is a common one.

### Air Dried Internal Coating For Steel Tank

**Based on successful experience, what air dried coating is recommended for the inside of a steel tank which is filled with distilled water?**

If the distilled water is not potable, coal tar epoxy formulas have worked very well in two-coat, 16-mill applications. Some coal tar epoxy products are usable at more elevated temperatures than others.

If the water is potable and must contain only raw materials approved by the Pure Food and Drug Administration, the most likely systems would be of vinyl chloride-vinyl acetate or epoxy formulation. The formulation of coatings for this service requires the use of solvents and other ingredients that do not leave taste in the water or released toxic constituents. To be taste-

free, vessels usually are force dried at low temperatures to remove all residual solvents. Therefore, require your supplier to be specific in his recommendations.

### Equipment for Zinc Silicate Coatings

**What type of equipment is being used to apply zinc silicate coatings?**

The equipment generally used by industry is of standard pressure feed air atomized type with minor modification. Guns are fitted with heavy duty needle springs and leather or Teflon feed packing.

Air agitated pots are equipped with double regulation and feed through over-sized fluid hoses.

*Fiberglass Reinforced*



**NYLON BUSHINGS**

Designed for Cathodic Protection use. Outstanding dimensional stability: Molded hex head equivalent to standard steel; black color for improved weathering resistance.

#### Maximum operating conditions:

TEMPERATURE ..... 300° F

PRESSURE ..... 1000 psi

SIZES AVAILABLE: 1/2 thru 2-inch

*Central Plastics*  
**DISTRIBUTING COMPANY**

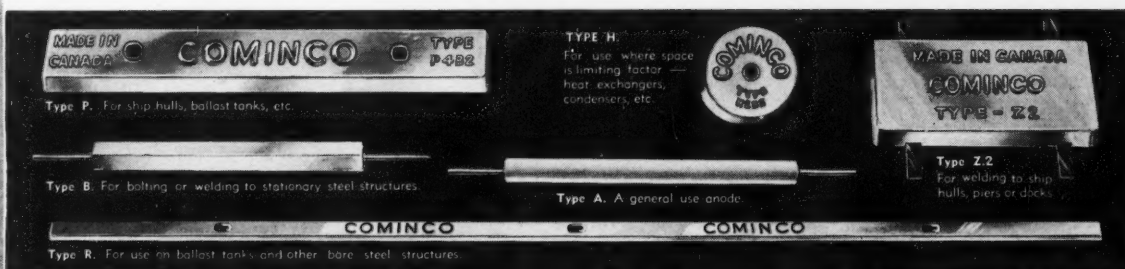
Box 762 SHAWNEE, OKLAHOMA

Prices and Literature on Request



# For Safe, Cathodic Protection

# *Specify* **COMINCO BRAND ZINC ANODES**



AVAILABLE IN A WIDE RANGE OF SHAPES AND SIZES TO PREVENT CORROSION OF STEEL WITH MAXIMUM ECONOMY.

- COMINCO BRAND ZINC ANODES do not require complex installation and will not overprotect, thus giving **maximum anode life**.

- They are **self-regulating**, automatically increasing or decreasing current supply as changing conditions may require.

- COMINCO BRAND ZINC ANODES are made from electrolytically refined Special High Grade Zinc to which carefully controlled additions have been made.

- They are **especially designed** for different services such as **ship hulls, ballast tanks, piers and docks, heat exchangers and pipe lines**. The requirements of these services indicate specific design is neces-

sary to give maximum economy and effectiveness.

- Many new anode designs have been developed by Cominco as a result of recent research. Of particular importance is the range of **new, long thin shapes** which tests have shown combine the advantages of **high current output per pound, improved self-regulating properties, less weight and lower capital cost**.

- COMINCO BRAND ZINC ANODES are designed for **easy installation** either by bolting or welding to the structure to be protected. All anodes have a **specially-designed insert** bonded to the anode metal, giving a permanent positive electrical connection for the full life of the anode.

To help you achieve effective cathodic protection—our Technical Service will be glad to be of assistance.

Write for our descriptive brochure on **COMINCO BRAND ZINC ANODES**.

## COMINCO

THE CONSOLIDATED MINING AND SMELTING COMPANY OF CANADA LIMITED, MONTREAL

CATHODIC PROTECTION WITH **ZINC** IS COMPLETE PROTECTION

Available in Eastern Canada from CORROSION SERVICE LIMITED, 17 Dundonald Street, Toronto 5, Ontario and in Western Canada from CAPROCO CORROSION PREVENTION LTD., 898 River Drive, Richmond, Vancouver, B.C.





# CORROSION ABSTRACTS

## INDEX TO CORROSION ABSTRACTS

Vol. 17 November, 1961 No. 11

### 3. CHARACTERISTIC

#### CORROSION PHENOMENA

- 3.2 Forms ..... 67  
3.8 Miscellaneous Principles ..... 68

### 5. PREVENTIVE MEASURES

- 5.3 Metallic Coatings ..... 70  
5.4 Non-Metallic Coatings and Paints ..... 71

### 6. MATERIALS OF CONSTRUCTION

- 6.3 Non-Ferrous Metals  
and Alloys—Heavy ..... 72  
6.6 Non-Metallic Materials ..... 75

### 7. EQUIPMENT

- 7.4 Heat Exchangers ..... 76  
7.5 Containers ..... 76  
7.6 Unit Process Equipment ..... 76

### 8. INDUSTRIES

- 8.10 Group 10 ..... 77

### 3. CHARACTERISTIC

#### CORROSION PHENOMENA

#### 3.2 Forms

##### 3.2.3, 7.4.1

Hard-Water Scaling of Finned Tubes at Moderate Temperatures. J. G. Knudsen and H. K. McCluer. Oregon State College. Chem. Eng. Progress, **55**, Symposium Ser. No. 29, 1-4 (1959).

With the increasing use of finned tubes in industrial heat transfer equipment it is important to know their heat transfer characteristics. This investigation is concerned with a study of the rate of scaling of transverse finned tubes in a double-pipe heat exchanger. (auth.)—NSA. 19942

##### 3.2.3, 6.2.3

Study of Mill Scale Formed on Steel Sheet During Hot Rolling. M. Cagnet and J. Moreau. (In French.) Rev. Mét., **57**, 437-444 (1960) May.

General characteristics of scale formed on three grades of extra-mild carbon steel studied by micro-examination of

polished specimens. Type of rolling mill, final rolling temperature and location from which specimen is taken influence thickness, compactness and adherence of oxide layer and shape of metal-oxide interface. Grade of steel appears to be unimportant in range studies. 7 references.—RML. 21250

##### 3.2.3, 3.8.4, 6.2.2

The Breakdown of the Protective Oxide Film on Transition Metal Alloys. W. W. Smeltzer. Acta Metallurgica, **8**, 268-270 (1960) April.

Initial breaks in oxidation curves of iron-chromium alloys were found to be associated with the ferrite-austenitic phase transformation. This transformation was caused by preferential oxidation of chromium at a rate much larger than its replenishment by diffusion to the metal-oxide interface. The stress resulting from this transformation caused breakdown of the protective oxide film. Results indicated that continuous oxidation curves for iron-chromium alloys could be obtained under conditions where preferential oxidation of an alloy constituent did not cause the ferritic-austenitic phase transformation.—NSA. 21079

##### 3.2.2, 3.7.3, 4.6.2, 7.2, 6.2.3

Weld Probe Sampling Programs of Graphitized Piping Are Still Your Best Guarantee of Safety of Carbon-Molybdenum Steel Steam Piping Systems. H. Thielsch. Grinnell Co., Inc. Heating, Piping & Air Conditioning, **31**, No. 3, 116-120 (1959) Mar.

Piping failures due to severe graphitization occur in less than 2% of carbon-molybdenum steel joints in steam piping systems operating at above 800 F within first 10 years of operation. Potentially severe cases of graphitization can be caught by following periodic sampling of joints. Weld sample may be removed by drilling or weld prober saw. Program should include removal of 1 specimen each from 30-50% of pipe-to-pipe joints involving wrought materials. Where sampling reveals graphitization to dangerous degree, rehabilitation can be accomplished by solution heat treatment, by gouging out graphitized zone and depositing new weld, or by replacement of carbon-molybdenum steel with chromium-molybdenum alloy steel not considered susceptible to graphite formation.—INCO. 18571

##### 3.2.2, 3.8.4

Pits in Metals Caused by Collision with Liquid Drops and Soft Metal Spheres—Research Paper No. 2958. O. G. Engel. National Bureau of Standards. J. Research Nat. Bureau of Standards, **62**, No. 6, 229-246 (1959) June.

An equation is developed to give pit depth as a function of collision velocity for pits formed in soft to medium-hard metal plates as a result of collision with liquid drops. Rear face of target plate must be a free surface. Plate thickness must not be less than 1.5-2.0 times drop diameter nor greater than 4-5 times drop diameter. Under same conditions on target plate, equation is also applicable

to pits formed in soft to medium-hard metal plates as a result of collision with spheres of same metal that flow radially as a result of collision. Pit-depth-versus-velocity data obtained in other labs were used to test equation. Metals used as targets were copper, aluminum, lead, steel, soft iron and zinc. Mercury was used as drop liquid against copper, aluminum, lead and steel. Water was used as drop liquid against copper, aluminum and lead. Spheres of copper, aluminum, lead, soft iron, and zinc were used against targets of same materials, respectively. Equation can be used to calculate dynamic compressive yield strength of soft to medium-hard metals. Tables, graphs, photomicrographs, 15 references.—INCO. 19103

##### 3.2.2, 6.2.3, 8.2.2

Graphitization Failures in Piping. J. B. Nuchols and J. R. McGuffey. Paper before American Society for Mechanical Engineers, Annual Meeting, New York, November 30-December 5, 1958. Mech. Eng., **81**, No. 5, 43-45 (1959) May.

Two unexpected major graphitization failures in carbon-molybdenum steel high-pressure main steam piping at Oak Ridge Gaseous Diffusion Plant Power Station in Sept. 1957 indicate potential hazards for power industry where comparable piping systems are still operating with carbon-molybdenum steel. Prior to first failure, a high level of confidence had been placed in program of selective sampling, partial replacement, and remedial repair of graphitized carbon-molybdenum steel piping system (including pipe joints, valve-to-pipe joints, superheater outlet headers and stubs, and castings and forgings executed in conjunction with scheduled inspection outages. Thorough evaluation

## PHOTOPRINTS and/or MICROFILM COPIES

of Technical Articles Abstracted in

## Corrosion Abstracts

May Be Obtained From

ENGINEERING SOCIETIES LIBRARY, 29 West 39th Street, New York 18, N. Y.

CARNEGIE LIBRARY OF PITTSBURGH, 4400 Forbes St., Pittsburgh 13, Pa.

NEW YORK PUBLIC LIBRARY, New York City.

U. S. DEPT. OF AGRICULTURE LIBRARY, Office of Librarian, Washington, D. C. (Special forms must be secured).

LIBRARY OF CONGRESS, Washington, D. C.  
JOHN CREAR LIBRARY, 86 East Randolph St., Chicago 1, Ill.

Persons who wish to secure copies of articles when original sources are unavailable, may apply directly to any of the above for copies. Full reference information should accompany request. The National Association of Corrosion Engineers offers no warranty of any nature concerning these sources, and publishes the names for information only.

NACE will NOT accept orders for photoprint or microfilm copies of material not published by the association.

Abstracts in This Section are selected from among those supplied to subscribers to the NACE Abstract Punch Card Service. Persons who are interested in reviewing all available abstracts should write to NACE for information on this service.



made possible during complete sampling of piping that failed revealed that there are factors in graphitization which cannot be readily predicted. Any unsampled component must be considered a potential graphitization failure. All carbon- $\frac{1}{2}$  molybdenum steel in system will be systematically replaced with  $1\frac{1}{4}$  chromium- $\frac{1}{2}$  molybdenum steel. Illustrations, photomicrographs.—INCO. 19345

### 3.2.2, 7.6.8

**Corrosion Inclination and Thickness Calculation of Furnace Tubes on Crude Distillation Unit.** (In Japanese.) Yahiko Kadono. *Corrosion Engineering*, 7, No. 6, 37-40 (1958) Nov.

Author measured inside diameter of furnace tubes to determine minimum wall thickness due to non-uniform corrosion. (1) Excessive corrosion due to blister formation is found on heating side of radiation tubes. (2) Minimum wall thickness of tubes is calculated by following equation:

$$T_m = T_o - \{(\Delta d \times (12.3 \sqrt{\Delta d} + 50)) / 100\}$$

$T_m$ : minimum thickness

$T_o$ : original thickness

$\Delta d$ : increase of inside diameter

—JSPS.

19317

### 3.2.3, 2.3.6, 2.3.9, 6.4.2, 6.2.2

**Electron-Microscope and Electron-Diffraction Study of Carburation of (Thin Films of) Iron and Aluminum.** (In French.) Jean-Jacques Trillat, (Mlle) Lea Tertian and (Mlle) Monique Bonnet-Gros. *Compt. rend.*, 249, No. 15, 1299-1302 (1959) October 12.

Carburization was followed by vacuum-depositing and heating iron or aluminum films on thin (100 Å) C membranes within the apparatus. With aluminum, no diffusion of carbon was observed up to 350 C, the diffraction patterns showing only rings from the aluminum but near 400 C supplementary rings appeared; these became more pronounced, and the aluminum rings more feeble, with increasing temperature. The practically pure dominant composition was observed at approximately 550 C and was identified as  $Al_4C_3$ . Towards 900 C, rings from crystallized  $\gamma-Al_2O_3$  appeared,

possibly, owing to oxidation of traces of uncombined aluminum, even under the high-vacuum conditions. Simultaneous electron-microscope studies showed a pattern change at approximately 900 C, indicative possibly of a mixture of  $Al_4C_3$  and  $Al_2O_3$ . A diffractographic record of the  $Al \rightarrow Al_4C_3$  transformation is presented.—MA. 19539

### 3.2.3, 6.2.2, 3.7.2

**Growth and Scaling of Cast Iron.** I. C. H. Hughes. *British Cast Iron Research Assoc.*, Rept. No. 526. *J. Brit. Cast Iron Research Assoc.*, 8, No. 1, 7-28 (1960) Jan.

Mechanisms of growth and scaling are explained and conditions which promote growth and scaling of cast iron are described. Influence upon growth and scaling of various alloying elements is considered. Small amounts of Ni have been reported to promote growth. Of high alloy austenitic irons, Nicrosil is most resistant to growth. Standard Ni-Resist possesses some growth resistance but greatly improved resistance is obtained in special grades of Ni-Resist with increased Cr contents. Improved resistance to scaling is found in Cralfer, Nicrosilal and Ni-Resist. Behavior of alloyed, flake and nodular cast irons in conditions promoting growth and scaling is described. Methods of measuring, calculating and predicting growth and scaling are also considered. Graphs, photomicrographs, 46 references.—INCO. 19813

### 3.2.2, 8.8.5, 3.8.2, 3.4.7, 3.4.8

**Environmental Factors Conducive to Graphite Corrosion.** R. I. Higgins. *British Cast Iron Research Assoc.* Rept. No. 535. *J. British Cast Iron Res. Assoc.*, 8, No. 2, 217-220 (1960) March.

Graphitic corrosion occurs where corrosion products of Fe matrix can escape from casting in soluble form. If final corrosion product is rust then it must be precipitated out of contact with cast iron surface. Chemical and electrochemical factors which favor graphitic corrosion are described on this basis. These include galvanic, applied e.m.f. or stray

current corrosion, low pH, presence of ions which form complexes with ferrous or ferric ions, low  $O_2$  concentration at metal surface, and presence of substances which peptize  $Fe(OH)_3$ . Diagrams.—INCO. 20001

### 3.2.2, 6.6.6

**Decarburization of Tungsten Carbide by Moist Hydrogen.** Hans Jürgen Booss. *Arch. Eisenhüttenwesen*, 30, No. 12, 761-764 (1959).

Mixtures of steam and hydrogen, with partial pressures of hydrogen of 30-75 mm Hg, were passed over WC samples of various degrees of fineness at temperatures from 800 to 1000 C for periods up to 4 hours. Rapid C analyses and X-ray examination of the final powder indicated that the activation energy of decarburization below 950 C was  $30.3 \pm 3$  kcal/mole, above 950 C  $53 \pm 8$  kcal/mole. It is concluded that the rate-determining step below 950 C is the desorption of CO from the WC lattice, above 950 C the diffusion of C through the WC lattice. Experiments in purified H indicated no decarburization at all.—MA. 20135

## 3.8 Miscellaneous Principles

### 3.8.2, 3.6.8, 6.3.11

**Proton Transfer Between Palladium|Hydrogen and Palladium-Platinum|Hydrogen Electrodes.** Pt. I. Equilibrium Hydrogen Electrodes. Pt. II. Incomplete Polarization of Proton Transfer. A. W. Carson, Ted B. Flanagan and F. A. Lewis. *Trans. Faraday Soc.*, 56, No. 9, 1311-1323; 1324-1331 (1960).

Pt. I. The drift of the resistance of Pt and Pt-Pd wires containing hydrogen was investigated as a function of proton transfer. Resistance measurements were used to examine the proton transfer between Pd|H and Pd-Pt|H electrodes and N-HCl when the situation was not complicated by H evolution. The activation energy of the process is 4.9 kcal/mole and the slow step seems to be the restriction in the permeation of the proton through a double layer. 15 references.

Pt. II. It is suggested that reversible concentration polarization of proton transfer may be incomplete when the H content of the Pd alloys corresponds to the co-existence of a number of hydride phases. The effect is evaluated for a number of palladium alloys and the measurement of resistance with incomplete polarization is discussed.—MA. 21241

### 3.8.4, 2.4.2, 6.3.20, 4.6.2, 3.5.9

**Metal-Water Reactions. Pt. IX. The Kinetics of Metal-Water Reactions—Feasibility Study of Some New Techniques.** Sydney C. Furman and Paul A. McManus. General Electric Co. U. S. Atomic Energy Commission Pubn., GEAP-3338, Jan. 31, 1960, 55 pp. Available from Office of Technical Services, U. S. Department of Commerce, Washington 25, D. C.

A feasibility study was carried out which demonstrated the ability of the Thermotot, a commercial radiometer, to follow temperature transients occurring as the result of zirconium-steam reaction. The instrument was employed to measure surface temperature at 1600 to 2300 C; the instrument is capable of covering a much wider range of temperature. In the study of the Thermotot, electromagnetic levitation melting of zirconium was developed. Zirconium

## Your Keys to 2136 Abstracts of Corrosion Control Literature

Containing 2136 abstracts of corrosion control literature published in 1956; 2859 authors alphabetically indexed. Comprehensive cross-references and subject index compiled according to the NACE Abstract Filing System. Improved referencing expedites use.

On sales to Texas addresses add 2% tax.

NON-MEMBERS  
\$27.50

NACE  
MEMBERS \$22.50

### For Full Cloth, Hard-Back Binding

Lettered in Gold Front and Back

ADDITIONAL  
PER COPY

\$5.75

NATIONAL ASSOCIATION of CORROSION ENGINEERS

1061 M & M Bldg.

Houston 2, Texas



## CONTENTS

1. Chronological tabulation of 969 articles and discussions thereto.
2. 38 pages of alphabetical subject index. Over 9000 entries.
3. An alphabetical list of 983 authors.

Size: 58 pages, 8¼ x 10¾ inches.  
Cover, paper. Saddlestitched.

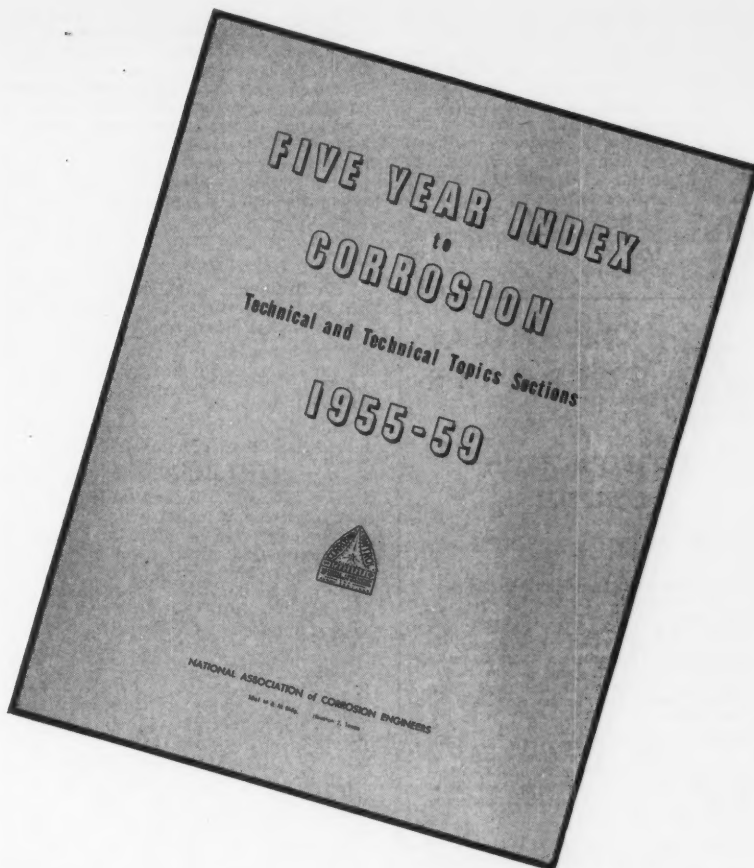
Per Copy  
NACE MEMBERS

**\$6**

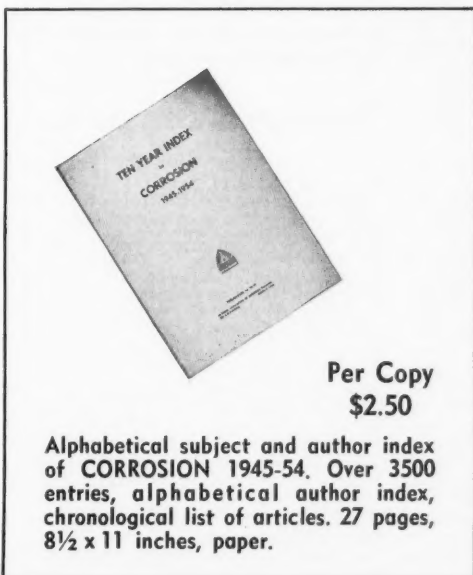
Non-Members ..... \$7.50

Add 75¢ for book post registry to addresses outside of U. S., Canada and Mexico.

On sales to Texas addresses add 2% tax.



# get answers to your problems in over 3350 pages of data



Per Copy  
**\$2.50**

Alphabetical subject and author index of CORROSION 1945-54. Over 3500 entries, alphabetical author index, chronological list of articles. 27 pages, 8½ x 11 inches, paper.

You can find answers easily to many of your corrosion control problems by referring to the complete, thorough alphabetical subject index in this book. It makes your back issue files as useful as this month's copy, and more, because it eliminates the need for remembering "where you saw it."

Because most technical material in CORROSION is about the work of engineers actually solving corrosion problems, this index is the key to data with a very high percentage of practical advice. Most articles are complete with figures, illustrations and tabulated data, to save your research time.

**NATIONAL ASSOCIATION  
of  
CORROSION ENGINEERS**

1061 M & M Bldg.

Houston 2, Texas

125a



was melted while suspended in a radio-frequency field. The design of coils required to obtain symmetric and relatively quiescent melts is discussed. Emissivities of oxidized and non-oxidized zirconium surfaces were measured at  $0.65 \mu$ , with an optional pyrometer and at  $2.3 \mu$  with the Thermot modified with a special filter. The considerations important in the interpretation of temperature measurements in regard to reaction rates are discussed. Suggestions for additional studies are made. (auth) —NSA. 20599



## TECHNICAL REPORTS

on

### CORROSION in UTILITIES

On sales to Texas addresses,  
add 2% tax.

TP-12 Report on Electrical Grounding Practices. Per Copy \$1.50.

T-4B Cell Corrosion on Lead Cable Sheaths. Third Interim Report of Technical Unit Committee T-4B on Corrosion of Cable Sheaths. Compiled by Task Group T-4B-1 on Corrosion of Lead and Other Metallic Sheaths. Publication No. 56-9. Per Copy \$1.50.

T-4B-2 Cathodic Protection of Cable Sheaths. Fourth Interim Report of Technical Unit Committee T-4B on Corrosion of Cable Sheaths. Compiled by Task Group T-4B-2 on Cathodic Protection. Publication 56-13. Per Copy \$4.00.

T-4B-3 Tests and Surveys for Lead Sheathed Cables in the Utilities Industry. Second Interim Report of Technical Unit Committee T-4B on Corrosion of Cable Sheaths. Publication 54-6. Per Copy \$5.00.

T-4B-4 Pipe-Type Cable Corrosion Protection Practices in the Utilities Industry. First Interim Report of Technical Unit Committee T-4B on Corrosion of Cable Sheaths. Publication 54-3. Per Copy \$4.00.

T-4B-6 Stray Current Electrolysis. Fifth Interim Report of Technical Unit Committee T-4B on Corrosion of Cable Sheaths, prepared by Task Group T-4B-6 on Stray Current Electrolysis. Publication No. 57-1. Per Copy \$2.50.

T-4B A Concentrator for Coordinated Corrosion Testing—A Contribution to the Work of NACE Tech. Unit Committee T-4B on Corrosion of Cable Sheaths, by Oliver Henderson and Louis Horbath. Pub. 57-26. Per Copy \$1.50.

T-4B Corrosion of Lead Sheath in Man-hole Water—A Contribution to the Work of NACE Tech. Unit Committee T-4B on Corrosion of Cable Sheaths. Pub. 58-6. Per Copy \$1.50.

TP-19 Corrosive Effects of Deicing Salts—A Progress Report by Technical Practices Committee 19. Corrosion, January, 1954, issue. Per Copy \$1.50.

T-4F-1 Progress Report of Task Group T-4F-1 on Water Meter Corrosion. Per Copy \$1.50.

Remittances must accompany all orders for literature the aggregate cost of which is less than \$5. Orders of value greater than \$5 will be invoiced if requested. Send orders to National Association of Corrosion Engineers, 1061 M & M Bldg., Houston, Texas. Add 75¢ per package to the prices given above for Book Post Registry to all addresses outside the United States, Canada and Mexico.

**NATIONAL ASSOCIATION  
OF CORROSION ENGINEERS**

1061 M & M Bldg. Houston 2, Texas

#### 3.8.4

On the Parabolic-Rate Law. W. B. Jepson. J. Electrochem. Soc., 107, No. 1, 53-55 (1960).

Jepson calculates the parabolic-rate constant,  $k_p$ , in terms of the defect concentration at one interface by introducing  $\Delta G$ , the free-energy change/mole, for the oxidation reaction.  $k_p$  is shown to be pressure-dependent and to have an exponential dependence of  $\Delta G$ . 12 references.—MA. 20812

#### 3.8.3, 3.2.2, 6.2.5, 4.3.2

The Influence of Anodic Polarization on the Intergranular Corrosion of Chromium-Nickel Stainless Steels. (In Russian.) N. D. Tomashov, G. P. Chernova and O. N. Markova. J. Applied Chem. (Zhur. Priklad. Khim.), 33, 1324-1334 (1960) June.

On the basis of previous findings which established that the corrosion resistance of stainless steels is increased several thousand fold by anodic polarization, a high C (0.15 to 0.25%), Ti-free Cr-Ni steel was used for further study of the effectiveness of anodic polarization against attack by a boiling solution containing  $160g\ CuSO_4 \cdot 5H_2O + 100\ ml\ H_2SO_4 + 1\ liter\ H_2O$ . Specimens were tempered at 1050 C and annealed at 650 C or tempered only. Potential measurements were used for establishing the passivity regions on the basis of the expression  $K_R/K_\infty > 1$  indicating the intergranular nature of the corrosive attack, where  $K_R$  refers to the experimentally determined resistance change and  $K_\infty$  to the resistance change calculated from the weight loss. It was established that from 0 to +0.3 v strong intergranular attack takes place because the grain boundaries are not yet passivated, while at potential values ranging from +0.51 to +0.83 v the intergranular attack is inhibited, as the steel is completely passivated, allowing only a slight general corrosion. The extent of the passive state of the annealed specimens as compared with the tempered ones was found to be considerably restricted. On increasing the aggressive nature of the attacking medium, the passive, corrosion-resistant region of the annealed steel is reduced to a greater extent than that of the tempered one. The same relative behavior exists also in the transpassivation zone. Anodic polarization was found effective in protecting the steel against attack by 10% nitric acid solutions containing up to 2% NaF.—NSA. 21058

#### 3.8.3, 6.2.5

Relation of Electron Configuration to Passivity in Cr-Ni-Fe Alloys. H. G. Feller and H. H. Uhlig. Massachusetts Inst. of Technology. J. Electrochem. Soc., 107, No. 11, 864-868 (1960) Nov.

Critical current densities for passivity were measured for single phase Cr-Ni-Fe alloys as a function of Cr content for 20%, 40%, 50% and 60% Ni compositions. Major discontinuities in slope approximate the ratio 12/88 for Cr to Fe in the 20 and 40% Ni alloy series, and 14/86 for Cr to Ni in the 50 and 60% Ni alloy series. These ratios correspond to observed critical compositions for passivity in the Cr-Fe and Cr-Ni binary systems. Additional discontinuities occur at the critical binary Cr to Fe ratio in the 50 and 60% Ni series. This behavior is interpreted in terms of separate electron interaction in the ternary system between Cr and Fe distinct from interaction between Cr and Ni. Flade or ac-

tivation potentials become more active with increasing Cr content, corresponding to increased stability of passivity. In accord with greater stability, average time for breakdown of passivity increased exponentially with Cr content. 21325

#### 3.8.2, 6.3.21

Electrochemical Behavior of Antimony: Equilibrium Potential/pH Diagram for the System Antimony-Water at 25 C. (In French.) A. L. Pitman, M. Pourbaix and N. de Zoubov. Proc. 9th Meeting Internat. Cttee. Electrochem. Thermodynamics and Kinetics (Paris, 1957), 1959, 32-46.

The diagram is constructed from the data for  $SbO^+$ ,  $SbO_2^+$ ,  $Sb(OH)_3$ ,  $SbO_2$ ,  $Sb(OH)_4^-$ ,  $H_2SbO_3$ ,  $Sb_2O_3$ ,  $Sb_2O_4$ ,  $Sb_2O_5$  and  $SbH_3$ . It is deduced that the potential/pH conditions for anodic and cathodic corrosion of Sb are separated by a region where Sb is immune. The solubilities of the oxides preclude passivation and cause Sb to be corroded by any solution containing an oxidizing agent. 29 references.—MA. 20873

#### 3.8.2, 8.10.2

The Electrochemical Theory of Smelting and Related Reactions. Technical Report No. 36. Xavier de Hemptinne, Henry Eyring and Taiyue Ree. Inst. for the Study of Rate Processes, Utah Univ. U. S. Atomic Energy Commission Pubn., AECU-4504, Nov. 9, 1959, 43 pp. Available from Office of Technical Services, Washington, D. C.

The potentials and electrical current flowing at an interface between two phases as a result of chemical reactions which promote selective ion migration are examined. Results from related fields are used as a basis of understanding. Included are discussions of multi-barrier diffusion, diffusion of charged particles in an electric field, migration of ions through a uniform membrane, and effects of voltage changes in diffusion rates. Processes in which the diffusion of ions is coupled with an irreversible chemical reaction such as desulfurization of iron, photographic development and corrosion.—NSA. 20589

## 5. PREVENTIVE MEASURES

### 5.3 Metallic Coatings

#### 5.3.4

Electrophoresis—A New Coating Tool. R. A. Keeler and L. C. Termello. Vitro Labs. Am. Machinist, 103, No. 10, 138-139 (1959) May 18.

Phenomena of electrophoresis and electro-osmosis are employed for applying Mo on steel, SiC bonded with Ni on mild steel, MoSi<sub>2</sub> on graphite, Ni-Cr on Mo, and MoSi<sub>2</sub>-Cu on stainless. Electrophoretic deposition is usually carried out in 4 or 5 separate steps, depending on materials to be deposited, including: preparation, deposition, reduction (if necessary), isostatic pressing, and sintering (bonding). Electro-osmotic impregnation differs from electrophoretic deposition in that impregnation of pores takes place, instead of deposition. Industrial applications include coating of graphite with oxidation- and erosion resistant materials, high-temperature wear-resistant lubrication coatings such as B-nitride-Cu-Ni on stainless; coatings such as Cr on Inconel, Mo on Inconel, and Mo on



Croloy which exhibit unusual resistance to molten metals for pump lining applications; and coatings of interest to nuclear industry such as  $UO_2$ -Ni (20-80%) on stainless, Ce oxide-Ni on steel, Inconel on mild steel, and Fe-Ni-Cr on Cu and steel. New processes are under development. Photomicrographs of coatings of Mo on Inconel and Ni-WC on steel.—INCO. 21385

#### 5.3.4, 6.3.19

**Formation of Zinc Coatings and Influence of the Grade of Zinc.** (In French.) A. Herz. *Métallurgie*, 91, No. 10, 753-755 (1959) October.

The author discusses the influence of impurities on the corrosion of zinc and examines the formation of galvanized coatings. The coating formed depends on the underlying metal, its surface preparation, the quality of the zinc and its temperature, the fluxing, the time of immersion and the speed of withdrawal. The article discusses the effects on the coating of impurities in the bath and mentions the crystallographic system and composition of the various layers which are produced. 2 tables.—ZDA. 21406

#### 5.3.4, 5.9.2, 2.2.2

**Atmospheric Corrosion-Resistance of Nickel-Plated Sheet Steel.** E. Raub, F. Elser and G. Schmidt. *Metallüberfläche*, 13, No. 10, 330-336 (1959).

Investigation designed to elucidate influence of basis metal on corrosion resistance, using various techniques of electrolytic degreasing. Three series of tests were made on steel sheets: as-plated with 10-micron matt nickel from Watts bath without after treatment; after polishing; and with copper underlayer of 10 microns. Exposures were made in moderately industrial atmosphere. For equal mean deposit thickness, nickel plating over copper underlayer gives better corrosion resistance than single layer of nickel. However, copper underlayer was polished. Coatings incorporating copper underlayer generally exhibit lower number of larger corrosion pits. In addition, there appears to be greater susceptibility to rust formation at surface defects underneath deposit. Open-hearth steel specimens have somewhat higher corrosion-resistance than bessemer steel specimens subjected to same pretreatment and nickel-plating cycle. Nickel-plated killed steel has lower corrosion resistance than rimmed steel. These differences are not pronounced and disappear on use of copper underlayer. Different electrolytic degreasing treatments do not have great effect on corrosion resistance of nickel plated steel, provided degreasing and cleaning are complete. In silicon or aluminum-killed steel purely anodic degreasing as well as degreasing involving alternating cathodic and anodic treatment raise susceptibility to filamentary corrosion and corrosion beneath deposit. Tables, photos of specimens. 11 references.—INCO. 20055

### 5.4 Non-Metallic Coatings and Paints

#### 5.4.5, 2.3.7

**Adhesion of (Paints) to Steel Panels.** K. R. Esters. *Farbe u. Lack*, 65, No. 5, 268-269 (1959).

Fifty commercial products were tested both as air drying and stoving films on steel using Erickson and other mechanical techniques. One weakness of the coatings was in resistance to swelling by water. Red lead and zinc chrome increased corrosion resistance;  $TiO_2$ , talc, slate powder and red iron oxide improved adhesion. The other pigments tested caused deterioration of water resistance or embrittlement of the film.—RPI. 20051

#### 5.4.5

**Problem of Painting Rusty Steel.** J. E. O. Mayne. *J. Applied Chem.*, 9, Pt. 12, 673-680 (1959).

Rust on steel specimens exposed in Cambridge always contains ferrous sulfate, the amount of which is lowest in July and highest in Jan.-Feb. It is

shown that rust catalyzes the oxidation of  $SO_2$  in the air to  $SO_3$ . Paint applied to rusty steel when the ferrous sulfate content is lowest has the best durability. A "limpet cell" is described for the determination of ferrous sulfate on structures in situ. The implications to the practical painting of rusty structures are discussed.—RPI. 20048

#### 5.4.2

**Sprayed Ceramic Coatings.** J. Alan Sheppard. *Eng. Materials Design*, 3, No. 5, 288-290 (1960).

Sprayed coatings of  $Al_2O_3$  or  $ZrO_2$  offer high thermal and abrasion resistance. Both can be applied through a Metco Thermospray gun, which requires no compressed air, since both O and  $C_2H_2$  both propel and melt the particles. A deposit efficiency >95% makes for high spraying speeds at low cost. A 1-mil coat of  $Al_2O_3$  can be applied at 150 ft<sup>2</sup>/h, and  $ZrO_2$  at little less than half this speed. The base metal should be pre-blasted.—MA. 21005

#### 5.4.2, 6.6.4, 3.5.9, 5.3.2

**Electrokinetic Processes—Nuclear Aspects.** Quarterly Progress Rept. for Feb. 1—Apr. 30, 1957. Vitro Job 2091. A. C. Werner and H. Katz. Vitro Labs. U. S. Atomic Energy Commission Pubn., KLV-10077, May 15, 1957 (Declassified June 10, 1960), 9 pp. Available from Office of Technical Services, Washington, D. C.

A number of coatings was investigated for protection of graphite against high-temperature oxidation and erosion. Well-sintered, well-bonded silicon carbide coatings were obtained by depositing elemental silicon on graphite, densifying, and sintering in CO at 1300 to 1400 C. However, the coatings were not perfect since complete protection was not offered against oxidation. A 75-15-10 nickel-chromium-silicon alloy sintered at 1100, 1200, and 1300 C wet graphite very well, whereas coatings with high metallic luster were obtained at the higher temperatures. Ferral, alumina, and chromium-silicon-iron-aluminum alloys were deposited electropho-



## TECHNICAL REPORTS

on

## PIPE LINE CORROSION

On sales to Texas addresses, add 2% tax.

**T-2** Statement on Minimum Requirements for Protection of Buried Pipe Lines. Prepared by a Special Task Group of NACE Technical Group Committee T-2 on Pipe Line Corrosion. Publication No. 56-15. Per Copy \$1.50.

**TP-2** First Interim Report on Galvanic Anode Tests. (Pub. 50-2) NACE members, \$3; Non-members, \$5 Per Copy.

**TP-3** First Interim Report on Ground Anode Tests. (Pub. 50-1) NACE members, \$3; Non-members, \$5 Per Copy.

**T-2B** Final Report on Four Annual Anode Inspections. A Report of Technical Unit Committee T-2B on Anodes for Impressed Current. Publication 56-1. Per Copy \$3.00.

**T-2B** Use of High Silicon Cast Iron for Anodes. First Interim Report of Unit Committee T-2B on Anodes for Impressed Current. Publication No. 57-4. Per Copy \$1.75.

**T-2B-4** Second Interim Report on Use of High Silicon Cast Iron for Anodes by Task Group T-2B-4 Use of High Silicon Cast Iron for Anodes. Publication 59-16. Members \$1.50; Non-members \$2.00 Per Copy.

**T-2B-4** Third Interim Report on Use of High Silicon Cast Iron for Anodes by Task Group T-2B-4 Use of High Silicon Cast Iron for Anodes. Publication 59-17. Members \$1.50; Non-members \$2.00 Per Copy.

**T-2B-4** Fourth Interim Report on Use of High Silicon Cast Iron for Anodes. A Report of Technical Unit Committee T-2B, Prepared by NACE Task Group T-2B-4 on High Silicon Cast Iron Anodes. Publication 60-3. Per Copy \$1.50.

**T-2C** Some Observations on Cathodic Protection Potential Criteria in Localized Pitting. A Report of T-2C on Minimum Current Requirements for Cathodic Protection. Pub. 54-2. Per Copy \$1.50.

**T-2C** Some Observations on Cathodic Protection Criteria. A contribution to the work of NACE Technical Unit committee T-2C. Publication No. 57-15. Per Copy \$2.00.

**T-2C** Criteria for Adequate Cathodic Protection of Coated, Buried, Submerged Steel Pipelines and Similar Steel Structures. A Report of NACE Technical Unit Committee T-2C on Criteria for Cathodic Protection. Pub. 58-15. Per Copy \$1.50.

**T-2D** Methods for Measuring Leakage Conductance of Coating on Buried or Submerged Pipe Lines—A Report of Tech. Unit Committee T-2D on Standardization of Procedures for Measuring Pipe Coating Leakage Conductance. Pub. 57-27. Per Copy \$1.50.

**T-2G** Tentative Recommended Specifications and Practices for Coal Tar Coatings for Underground Use. A Report of Technical Unit Committee T-2G on Coal Tar Coatings for Underground Use. Per Copy \$1.50.

**T-2H** First Interim Report. Tentative Recommended Specifications for Asphalt Type Protective Coatings for Underground Pipe Lines—Wrapped Systems. A Report of NACE Technical Unit Committee T-2H on Asphalt-type Pipe Coatings. Publication No. 57-11. Per Copy \$1.50.

**T-2H** Second Interim Report. Tentative Recommended Specifications for Asphalt-type Protective Coatings for Underground Pipe Lines—Mastic Systems. A Report of NACE Technical Unit Committee T-2H on Asphalt-type Pipe Coatings. Publication No. 57-14. Per Copy \$1.50.

**T-2H** Tentative Recommended Specifications for Asphalt-Type Protective Coatings for Underground Pipelines (Minimum Recommended Protection). A Report of NACE Technical Unit Committee T-2H on Asphalt Type Pipe Coatings. Pub. 58-12. Per Copy \$1.50.

Remittances must accompany all orders for literature the aggregate cost of which is less than \$5. Orders of value greater than \$5 will be invoiced if requested. Send orders to National Association of Corrosion Engineers, 1061 M & M Bldg., Houston, Texas. Add 2% per package to the prices given above for Book Post Registry to all addresses outside the United States, Canada and Mexico.

## NATIONAL ASSOCIATION OF CORROSION ENGINEERS

1061 M & M Bldg. Houston 2, Texas



retically on graphite. Although excellent green coatings were obtained, sintered coatings were poor. The fecal coatings did not wet the surface, and the alumina coatings were brittle and non adherent indicating that a higher temperature was necessary. (auth)—NSA. 21231

#### 5.4.2, 6.4.2

**Enamels for Aluminium Based on the Lead Phosphate-silicate System.** (In Russian.) M. A. Bezborodov, E. E. Mazo and V. S. Kaminskaya. Glass & Ceramics, Moscow, 17, No. 1, 35 (1960).

In the system  $K_2O-PbO-Al_2O_3-P_2O_5-SiO_2$  glasses were obtained on the basis of which low-melting enamels can be made. The chemical stability of these glasses is ensured by introducing  $Al_2O_3$ . To improve adherence  $B_2O_3$  6-8% is introduced. Recipes are given. Enamel 264 is white ( $MoO_3$  2% is added to the mill). Enamel No. 257 is used with various colors to give red, orange, pink, lilac, blue, green, etc. To prevent the reduction of lead during the firing of colored enamels,  $Ba(NO_3)_2$  0.25-0.5% is introduced. The enamels mature at 540-580 C. They are stable in 4% acetic acid and their thermal expansion lies between 152 and  $177 \times 10^{-7}$ .—LMB. 20459

#### 5.4.5, 5.9.4

**Phosphorus Derivatives in the Modern Paint and Varnish Industry.** (In French.) R. Dumon. Peintures, Pigments, Vernis, 35, No. 1, 4-7 (1959).

Some of the uses mentioned are: use of phosphoric acid and phosphates for the preparation of metal surfaces; wash primers based on chromium phosphate or organic derivatives of phosphoric acid (e. g., butyl phosphoric acid) for improving adhesion; alkali salts of phosphoric acids for pigment dispersion and to stabilize emulsions; organophos-

phorus compounds (e. g., tricresyl phosphate) as solvents, plasticizers and antifoaming agents, for improvement of flame resistance, and as polymerization catalysts in varnish making.—RPI. 19087

#### 5.4.5

**Paint Versus Corrosion.** K. C. Duffy. Australian Corrosion Eng., 3, No. 3, 25-29 (1959) March.

Theory of corrosion by destruction of the paint film is outlined. In the section dealing with corrosion prevention, mention is made of 'zinc-rich paints' and zinc chromate pigments.—ZDA. 19080

#### 5.4.5, 5.9.4

**Protective Coatings for Steel Drums.** Association of British Chemical Manufacturers, Packaging Committee Rept. Paint, Oil & Col. J., 135, No. 3156, 779-780 (1959). See also: Paintindia, 9, No. 2, 27-28 (1959).

Opinions expressed in the report suggest that a phosphate coating in itself does not retard corrosion but provides a sound basis for the application of a protective film. The use of lacquer coatings is also discussed; although polyurethane and epoxy lacquers provide extreme chemical resistance and flexibility, a two-lacquer system is favored, the first coat having high adhesion and flexibility and the second coat high chemical resistance.—RPI. 19017

#### 5.4.5, 6.3.19, 8.9.1

**Paints and Lacquers. Questions and Answers.** (In Serbo-Croat.) I. Vuckovic. Zastita Materijala (Protection of Material), 7, No. 5, 241-243 (1959).

Author answers in some detail the following questions: (1) why zinc, zinc alloys and galvanized iron surfaces are difficult to paint and why zinc surfaces

corrode; (2) what kind of specific failures occur in the lacquering of aeroplanes; (3) what kind of failures of media lead to flaking and the appearance of rust.—RPI. 18584

#### 5.4.5

**Anti-Corrosion Behavior of Zinc-Rich Paints.** (In German.) Hans Sagel. Werkstoffe u. Korrosion, 10, No. 2, 66-70 (1959) Feb.

Decrease in corrosion of structural steel and sheet exposed to atmospheric conditions is achieved by painting the surfaces with zinc-rich paints composed of zinc dust (60% metallic zinc), polystyrol and solvents. 16 references.—RML. 18640

## 6. MATERIALS OF CONSTRUCTION

### 6.3 Non-Ferrous Metals and Alloys—Heavy

#### 6.3.15, 3.8.3, 3.7.2, 3.5.9, 3.4.4

**Increasing the Stability of the Passive State in Titanium.** (In German.) N. D. Tomashov, G. P. Tshchernova and R. M. Altowski. Z. Phys. Chem. (Leipzig), 214, No. 5/6, 312-323 (1960). The behaviour of titanium and its alloys with 1% and 2% of platinum and palladium on cathodic and anodic polarization in  $H_2SO_4$  and HCl solutions was studied by potentiostatic methods. It was shown that the complete passivation of titanium is made more difficult by increasing the temperature and concentration of the acid solution. The alloys of titanium with platinum and palladium have a substantially higher corrosion stability than titanium. Titanium may be protected anodically in  $H_2SO_4$  and HCl of all concentrations and may be passivated by cathodic depolarizers such as ions of  $Pt^{4+}$ ,  $Cu^{2+}$  and  $Fe^{3+}$  in the corrosive medium.—PMR. 21059

#### 6.3.6, 3.7.4, 2.3.6, 5.9.4

**Stacking Faults and the Failure of Alloys in Corrosive Media.** P. R. Swann and J. Nutting. J. Inst. Metals, 88, No. 11, 478-480 (1960) July.

Electron-optical examination of thin foils of copper-zinc and copper-aluminum alloys has shown that during electropolishing preferential attack may occur along stacking faults, while in copper-germanium and copper-silicon alloys the matrix is preferentially attacked. The relevance of these observations to the formation of cracks in corrosive media is discussed. 7 figures, 8 references.—ZDA. 21050

#### 6.3.10, 8.4.5

**Corrosion of INOR-8 and Inconel Dissolver Components of the Fluoride-Volatility Process.** F. W. Fink. Battelle Memorial Inst. U. S. Atomic Energy Commission Pubn., AECU-4633, December 30, 1959, 50 pp. Available from Office of Technical Services, Washington, D. C.

The corrosion of INOR-8 and Inconel dissolver components used in the fluoride volatility process for the dissolution of zirconium with anhydrous HF in molten salts was investigated. Ten dissolution runs were made using simulated subassemblies formed from Zircaloy-2. The dissolver and components were made from INOR-8. Both the dissolver vessel and draft tube were



## Proceedings SHORT COURSE on PROCESS INDUSTRY CORROSION

Twenty-two papers presented Sept. 12-16 at the symposium sponsored jointly by Ohio State University and NACE Technical Group Committee T-5 on Corrosion Problems in the Process Industries. The 450-page book measures 8½ x 11 inches, has a plastic back, flat opening. Many tables, graphs and illustrations; hundreds of references.

On sales to Texas addresses, add 2% tax.

PER  
COPY  
U.S., CANADA  
and MEXICO

**\$20 NACE Members**  
**\$25 Non-Members**

Add 75¢ per package to the prices given above for Book Post Registry to all addresses outside the United States, Canada and Mexico.

These papers are by engineers concerned with controlling corrosion in some of the nation's largest chemical processing plants. Considered are use of metal and plastic materials in a wide variety of environments, including most of the common acids and alkalis; special problems found in both low and high temperature processes, corrosion measurements, coatings, design and other practical information.

Send Orders and Remittances to

**National Association of Corrosion Engineers**  
1061 M & M Bldg. Houston 2 Texas



examined several times during the series of runs. The solids which formed at different areas in the system were also analyzed. The results showed that the corrosion of the INOR-8 dissolver was greatest at the salt-off gas interface and at the HF gas inlet. Almost all of the corrosion took place during run 10 when no Zr was present. Portions of the dissolver were cleaned after run 10 and sent to BMI for evaluation. The results of the Battelle metallographic examinations of the portions are included along with several photographs. The results with Inconel tubes in the copper-lined hydrofluorinator confirmed the observations that the liquid gas interface areas were most susceptible to attack.—NSA. 20605

### 6.3.15, 3.2.2, 3.5.9

**Low-Temperature Recovery of Ductility in a Hydrogen-Embrittled Alpha/Beta-Titanium Alloy.** F. R. Schwartzberg, D. N. Williams and R. I. Jaffee. *J. Inst. Metals*, **88**, No. 8, 352-356 (1960).

Tensile tests performed at various temperatures, strain rates, and hydrogen levels allowed an activation energy to be calculated for the embrittlement process in H-containing Ti-Fe 2-Cr 2-Mo 2% alloy. The activation energy based on the recovery of ductility at low temperature is similar to that for diffusion of H in unalloyed  $\beta$ -Ti. Thus, it was concluded that the recovery of

ductility is a rate-controlled process related to the diffusion of H in the  $\beta$  phase of the two-phase alloy. (arh)—MA. 21048

### 6.3.5, 6.3.9, 3.7.2, 5.3.2

**Development of Oxidation Resistance of Some Refractory Metals.** G. L. Miller and F. G. Cox. *Journal of the Less-Common Metals*, **2**, No. 2-4, 207-222 (1960) April-August.

Investigations into the protection of niobium and molybdenum from oxidation by alloying and by coating are described. **Niobium Alloys.** In a preliminary part of the work, niobium binary alloys (including some with 1, 5 and 20 at.% Co), were oxidation tested at 1000 C. The results led to the selection of Ti, Al and Cr as addition elements for ternary alloys. Two ternary compositions (in at.%) gave considerable promise: 60Nb-20Al-20Cr and 60Nb-20Al-20Ti. Further additions were made to these alloys, and cobalt was particularly beneficial, reducing the oxidation rate of the Nb-Al-Cr alloy from 2.95 to 1.6 mg/cm<sup>2</sup>/h for the 60:17.5:17.5 Nb-Al-Cr-Co alloy. However, since these alloys were brittle and had melting points as low as 1400 C, development along these lines was abandoned.

Efforts were then concentrated on alloys of Nb with refractory metals, and the test temperature was raised to 1200 C. At this temperature, the most promising alloying elements were W

and Ti. The best results were obtained with a Nb-20W-20Ti alloy. The next step was to investigate the addition of 5 at.% of other elements to the above base in substitution for part of the W and Ti. Fe, Ni and Co were particularly beneficial, reducing by one third the oxidation rate of the ternary alloy. Increasing the Co content to 16.7 at.% proved to be highly detrimental. **Molybdenum—Protection by Coating.** Two coatings were investigated; a Ni-Cr-B alloy and an Al-Cr-Si alloy. The second affords protection against oxidation at 1200 C for 150-200 hrs, and exhibits adequate resistance to thermal shock. **Niobium—Protection by Coating.** Many alloys, including some cobalt alloys, were tried without success.—CO. 21061

### 6.3.6, 3.2.2, 3.5.8, 4.3.1, 4.6.1

**Copper and Its Alloys, Classes and Types, Corrosion Characteristics and Applications.** A. W. Tracy. pp. 83-97 of *Proceedings Short Course on Process Industry Corrosion*. Book, 1960. National Association of Corrosion Engineers, 1061 M & M Building, Houston 2, Texas.

One of 22 papers presented during the short course at Ohio State University, September 12-16, 1960. Corrosion characteristics of copper alloys are considered. Effects discussed are dezincification, pitting, stress-corrosion cracking, fatigue and galvanic. Uses of the



## TECHNICAL REPORTS

on

### Corrosion in Oil and Gas Well Equipment

On sales to Texas addresses, add 2% tax.

**T-1A** Survey of Corrosion Control in California Pumping Wells. A Report of T-1A on Corrosion in Oil and Gas Well Equipment, Los Angeles Area. Pub. 54-7. Per Copy \$1.50.

**TP-1** Report on Field Testing of 32 Alloys in the Flow Streams of Seven Condensate Wells (Pub. 50-3) NACE members, \$8; Non-members, \$10 per Copy.

**T-1B-1** Well Completion and Corrosion Control of High Pressure Gas Wells—A Status Report of NACE Task Group T-1B-1 on High Pressure Well Completion and Corrosion Mitigation Procedure. Pub. 59-6. Per Copy \$1.50.

**T-1C** Current Status of Corrosion Mitigation Knowledge on Sweet Oil Wells. A Report of Technical Unit Committee T-1C on Sweet Oil Well Corrosion. Per Copy, \$1.50.

**T-1C** Field Practices for Controlling Water Dependent Sweet Oil Well Corrosion. A Report of Technical Unit Committee T-1C on Sweet Oil Well Corrosion, Compiled by Task Group T-1C-1 on Field Practices. Pub. No. 56-3. Per Copy \$1.50.

**T-1C** Status of Downhole Corrosion in the East Texas Field—A Report of NACE Tech. Unit Committee T-1C on Sweet Oil Well Corrosion. Pub 57-23. Per Copy \$1.50.

**T-1C** Water Dependent Sweet Oil Well Corrosion Laboratory Studies—Reports of NACE Tech. Unit Committee T-1C on Sweet Oil Well Corrosion. Pub. 57-24. Per Copy \$2.50.

**T-1C** Theoretical Aspects of Corrosion in Low Water Producing Sweet Oil Wells—A Status Report of NACE Tech. Unit Committee T-1C Prepared by Task Group T-1C-4. Pub. 58-4. Per Copy \$1.50.

**T-1C** Experience With Sweet Oil Well Tubing Coated Internally With Plastic—A Status Report of Unit Committee T-1C on Sweet Oil Well Corrosion. Pub. 58-8. Per Copy \$1.50.

**TP-1D** Sour Oil Well Corrosion. *Corrosion*, August, 1952, issue. \$1.50 Per Copy.

**TP-1G** Field Experience With Cracking of High Strength Steel in Sour Gas and Oil Wells. (Included in Symposium on Sulfide Stress Corrosion.) (Pub. 52-3) NACE Members \$3.50; Others \$5.00 Per Copy.

**T-1G** Sulfide Corrosion Cracking of Oil Production Equipment. A Report of Technical Unit Committee T-1G on Sulfide Stress Corrosion Cracking. Pub. 54-5. \$1.75 Per Copy.

**T-1G** Hydrogen Absorption, Embrittlement and Fracture of Steel. A Report on Sponsored Research on Hydrogen Sulfide Stress Corrosion Cracking carried on at Yale University, Supervised by NACE Technical Unit Committee T-1G on Sulfide Stress Corrosion Cracking by W. D. Robertson and Arnold E. Schuetz. Pub. 57-17. Per Copy \$5.50.

**T-1J** Status Report of NACE Technical Unit Committee T-1J on Oil Field Structural Plastics. Per Copy \$1.50.

**T-1J** Reports to Technical Unit Committee T-1J on Oilfield Structural Plastics. Part 1—Long-Term Creep of Pipe Extruded from Tenite Butyrate Plastics. Part 2, Structural Behavior of Unplasticized Geon Polyvinyl Chloride. Publication 55-7. Per Copy \$2.75.

**T-1J** Summary of Data on Use of Structural Plastic Products in Oil Production. A Status Report of NACE Technical Unit Committee T-1J on Oilfield Structural Plastics. Per Copy \$2.75.

**T-1J** Service Reports Given on Oil Field Plastic Pipe. Activities Report of T-1J on Oilfield Structural Plastics. Per Copy \$1.75.

**T-1J** Oilfield Structural Plastics Test Data are given. Activities Report of T-1J on Oilfield Structural Plastics. Per Copy \$1.75.

**T-1J** Reports to Technical Unit Committee T-1J on Oil Field Structural Plastics. Part 1—The Long-Term Strengths of Reinforced Plastics Determined by Creep Strengths. Part 2—Microscopic Examination as a Test Method for Reinforced Plastic Pipe. Per Copy \$1.50.

**T-1J** Status Report of NACE Technical Unit Committee T-1J on Oil Field Structural Plastics. Part 1—Laboratory Testing of Glass-Plastic Laminates. Part 2—Service Experience of Glass Reinforced Plastic Tanks. Part 3—High Pressure Field Tests of Glass-Reinforced Plastic Pipe. Per Copy \$1.50.

**T-1J** Service Experience of Glass Reinforced Plastic Tanks—Status Report of NACE Technical Unit Committee T-1J on Oil Field Structural Plastics. Pub. 57-18. Per Copy \$1.50.

**T-1J** Experience with Oil Field Extruded Plastic Pipe in 1955—A Report of NACE Technical Unit Committee T-1J on Oil Field Structural Plastics. Pub. 57-19. Per Copy \$1.50.

**T-1K** Proposed Standardized Laboratory Procedure for Screening Corrosion Inhibitors for Oil and Gas Wells. A Report of T-1K on Inhibitors for Oil and Gas Wells. Publication 55-2. Per Copy \$1.50.

**T-1K-1** A Proposed Standardized Static Laboratory Screening Test for Materials to be Used as Inhibitors in Sour Oil and Gas Wells. A Report of NACE Technical Unit Committee T-1K on Inhibitors for Oil and Gas Wells, Prepared by Task Group T-1K-1 on Sour Crude Inhibitor Evaluation. Publication 60-2. Per Copy \$1.50.

**T-1M** Suggested Coating Specifications for Hot Application of Cool Tar Enamel for Marine Environment. A Report of NACE Technical Unit Committee T-1M on Corrosion of Oil & Gas Well Producing Equipment in Offshore Installations. Publication No. 57-8. Per Copy \$1.50.

**T-1M** Suggested Painting Specifications for Marine Coatings. A Report of NACE Technical Unit Committee T-1M on Corrosion of Oil & Gas Well Producing Equipment in Offshore Installations. Publication No. 57-7. Per Copy 1.50.

Remittances must accompany all orders for literature the aggregate cost of which is less than \$5. Orders of value greater than \$5 will be invoiced if requested. Send orders to National Association of Corrosion Engineers, 1061 M & M Bldg., Houston, Texas. Add 75¢ per package to the price given above for Book Post Registry to all addresses outside the United States, Canada and Mexico.

## NATIONAL ASSOCIATION OF CORROSION ENGINEERS

1061 M & M Bldg. Houston 2, Texas



materials with the following substances are discussed: Acids, alkalis, ammonia, salt solutions, organic compounds, gases, fresh water, sea water, steam, food products and atmospheres. There are two tables and eight figures. 21078

### 6.3.5, 3.7.2

**The Development of Oxidation-Resistant Niobium Alloys.** (In English.) R. Smith. *J. Less-Common Metals*, 2, No. 2-4, 191-206 (1960) April-August.

The mechanism of niobium oxidation is first reviewed. An account is then given of systematic investigations into the oxidation resistance of an extensive range of ternary and more complex alloys. The most promising base for the development of high-temperature high-strength alloys was found to be niobium alloys containing (in at.%) 15-25 Ti and 6-10 W since their creep strength is of the same order as that of niobium and their oxidation resistance is by far superior. The effect of nickel and cobalt additions on the oxidation rates in air at 1000 and 1100 C was investigated. The optimum addition level was found to be 4 at.%, in both cases, the nickel being however the more beneficial element of the two; the Nb-20Ti-10W-4Ni alloy has an oxidation resistance 100 times that of pure niobium.—PI. 20187

### 6.3.20, 3.2.2, 4.6.1, 3.8.4

**The Influence of Hydrogen on the Corrosion of Zirconium and Its Alloys in High Temperature Water.** (In French.) J. N. Wanklyn. *Atomic Energy Research Establishment*, Harwell, Berks, England, pp. 127-135 of "3<sup>e</sup> Colloque de Metallurgie sur la Corrosion

(Sèche et Aqueuse). Organise a Saclay les 29-30 juin et 1<sup>er</sup> juillet 1959." Saclay, France, Centre d'Études Nucléaires and North Holland Publishing Co., Amsterdam, Holland, 1960.

The influence of hydrogen on the corrosion of zirconium and its alloys was studied in two types of experiment; cathodic polarization during corrosion in water at 325 C and comparison of the oxidation of zirconium at 325 C in dry oxygen and in steam. Weight gain was used as the measure of corrosion, and also the protective character of the oxide films was estimated by measuring their capacities. Cathodic polarization was found to diminish the protective character of the films on zirconium and some of its alloys; but other alloys, including Zircaloy-2, were more resistant to polarization. The percentages of the cathodic hydrogen which entered the various alloys were very different, but there was no relation between these values and the extent of damage to the oxide films. The protective elements in Zircaloy-2 appear to act by stabilizing the oxide against the harmful effect of hydrogen, rather than by preventing the latter's entry into the metal. It is shown that, in the oxidation of zirconium, the presence of hydrogen causes increased cracking of the oxide, films formed in steam being, at a given thickness, less protective than those formed in dry oxygen. It seems, that in the initial stage of oxidation hydrogen can increase the rate of ionic diffusion in the oxide; but this is not in agreement with the final rates of oxidation formed in the two gases. The present picture of the oxidation process is probably too simple; and the mechanical properties of oxide films on metals require further study. (auth)—NSA. 21226

### 6.3.20

**Zirconium Highlights.** Westinghouse Electric Corp. Bettis Atomic Power Lab. U. S. Atomic Energy Commission Pubn., WAPD-ZH-24, May, 1960, 22 pp. Available from Office of Technical Services, Washington, D. C.

The effect of iron and O<sub>2</sub> variation on corrosion and hydrogen uptake behavior of Zircaloy-4 is being studied. Because nitrogen-rich inclusions were found in Zircaloy-2 cover plate stock, attempts were made to generate nitrogen-rich inclusions in Zircaloy fabricated products. The corrosion behavior of Zircaloy-2 with various levels of iron content was studied. An evaluation is presented of the powder produced from the electrolytic refining of Zircaloy machine scrap.—NSA. 21227

### 6.3.6, 8.2.2, 6.3.10, 4.6.1

**Corrosion of Copper-Nickel Alloys for Feed Water Heaters.** H. Urata, N. Kawashima and O. Asai. *Hitachi Review*, Spec. Issue, 37, 80-86 (1960).

Corrosion tests of copper-nickel alloys in water were carried out in the laboratory and actual power-generating plant, to investigate the cause of corrosion of 70/30 cupro-nickel in feed water heaters and at the same time clarify the relationship between corrosion resistance and the ratio of Cu/Ni. Monel showed excellent corrosion resistance in all corrosion tests. In water containing slight oxygen, corrosion resistance of 70/30 was better than that of 90/10. Under a condition of supplying oxygen periodically, however, corrosion resistance of 70/30 was most inferior as the protective action of the film formed on 70/30

was little. As a result of this experiment 70/30 is unsuitable for Japanese power-generating plants at which start and stop takes place frequently, causing more corrosion of 70/30. It is preferable to use Monel or 90/10 instead of 70/30 for that purpose.—INCO. 21181

### 6.3.19, 4.3.6, 3.8.2

**Corrosion of Zinc in Sodium Chloride Solutions.** J. Sedzimir and M. Gmytryk. In Polish: *Archiwum Hutnictwa*, 5, No. 1, 117-135 (1960); In German: *Werkstoffe u. Korrosion*, 11, No. 7, 410-416 (1960) July.

Corrosion tests have been carried out with 99.99% Zn in distilled water and in NaCl solutions with 30, 90 and 200 gram of NaCl per litre at 25 C. The quantity of corroded metal was determined polarographically after tests lasting 20, 40, 80, 160 and 320 minutes. In addition, the O and CO<sub>2</sub> content of the different solutions was determined and the potential of the corroding Zn specimens was measured. The tests show that: The corrosion rate of Zn increases during the initial stage of the reaction, with the increase of the NaCl concentration in the solution; When the corrosion rate decreases the relationship can be expressed by the following equation:  $\frac{dk}{dt} = A \cdot t^{-B}$  where B

ranges from 0 to 1; The potential of the corroding test specimen decreases as the NaCl concentration increases; The potential of the corroding test specimen also decreases with time.

An examination of the test results on the strength of the Nernst-Tafel formula shows that the share of the H depolarization is very small within the corrosion range investigated. By means of hypothetical polarization curves, it was possible to explain the influence of the NaCl concentration on the corrosion rate.

The increase of the Zn-corrosion rate in solutions with decreasing oxygen concentration indicates that the microelements in the system investigated work at current values below the critical oxygen current. 21017

### 6.3.10, 8.4.3

**High-Nickel Alloys in the Petroleum Industry.** G. L. Swales. *Corrosion Technology*, 6, Nos. 3, 4, 81-84, 119-123 (1959) March, April.

Part I of review of applications of high-nickel alloys in petroleum industry covers: applications of Monel for protection of offshore drilling structures; use of K Monel for non-magnetic drill collars; use of Monel, S. Monel and K. Monel for valves, pumps, gas-lift equipment, sucker rods, etc. in extremely corrosive wells; use of Monel in distillation of crude oil, Monel-clad distillation columns; resistance of Monel to acids; use of molybdenum bearing 18-8 and Inconel for equipment handling naphthenic acid-containing crudes; and use of Colmonoy 6 hard-facing alloy to resist erosion by high-velocity catalyst streams. Part II deals with use of Monel, Inconel, Incoloy, S. Monel, K. Monel, Nimonic DS, Ni-O-Nel, Corronel B, Langalloys, Hastelloys, Paralloys 20, Carpenter 20, Alloyco 20, Durimet 20, nickel and various stainless steels to combat specific corrosion problems in variety of refinery treating processes (hydrofluoric acid alkylation, sulfuric acid alkylation, acid treatment of distillates, isomerization, amine gas treatment, caustic treatment and furfural



## High Purity Water Corrosion of Metals

Seven papers presented at symposia at 1959-60 NACE Conferences. 108 pages, 8½ x 11, plastic binding, typescript. Per copy, NACE members \$7. Non-members, \$9.

On sales to Texas addresses, add 2% tax.

Remittances must accompany all orders for literature the aggregate cost of which is less than \$5. Orders of value greater than \$5 will be invoiced if requested. Send orders to National Association of Corrosion Engineers, 1061 M & M Bldg., Houston, Texas. Add 75c per package to the prices given above for Book Post Registry to all addresses outside the United States, Canada and Mexico.

**NATIONAL ASSOCIATION OF CORROSION ENGINEERS**

1061 M & M Bldg. Houston 2, Texas



treatment of lube oils). Consideration is given to requirements for high-temperature furnace tubes with emphasis on Inconel, Incoloy and 25-20 chromium-nickel steels. Mention is made of sigma phase formation in some austenitic steels.—INCO. 18563

### 6.3.20, 4.7, 3.8.2

**Equilibrium Potentials of Zirconium in Molten Fluoride-Chloride Mixtures.** (In Russian.) M. V. Smirnov, V. E. Komarov and A. N. Baraboshkin. Inst. of Electrochemistry Ural Div., Academy of Sciences, USSR. Doklady Akad. Nauk S.S.S.R., 133, 409-412 (1960) July 11.

Equilibrium potentials of zirconium were measured at 700 to 950 C in an equimolar mixture of sodium chloride and potassium chloride with various admixtures of fluorine. The melts contained 0.17 to 1.05 wt.% zirconium and up to 15.82 wt.% fluorine with the mole-fraction ratios (F/Zr) from 9 to 75. The experiments showed that in addition to a zirconium potential dependence on its concentration, it depends even more on fluorine concentration. In mixed fluoride electrolytes with high fluorine saturation,  $75 > (F)/(Zr) > 10$ , the mean zirconium valency  $n$  and mean number of fluorine ions in complex  $m$  fluctuate within the limits  $4 > n > 3$  and  $6 > m > 4$ . In approximate calculations it is assumed that  $m = 5$  and  $n = 3.2$ .—NSA. 21016

## 6.6 Non-Metallic Materials

### 6.6.6, 8.4.5, 7.7

**Beryllium Oxide and Its Properties.** (In Russian.) P. P. Budnikov and R. A. Belyaev. J. Applied Chem. (Zhur. Priklad. Khim.), 33, 1921-1940 (1960) Sept.

In view of its highly refractory character, good nuclear properties, satisfactory thermal shock resistance, and excellent chemical resistance, which make it very useful as structural material in high temperature reactors, the

available information on the physical and chemical properties of BeO is reviewed. This material is also useful for the manufacture of electrical insulators and phosphors, and it serves as a raw material for the preparation of metallic beryllium and beryllium alloys. It forms hexagonal, Wurtzite type crystals. Depending on the method of preparation, the density of the material ranges from 2.20 to 2.95 g/cm<sup>3</sup>, although it was reported that by hot-pressing the density of 3.01 g/cm<sup>3</sup> was reached. The melting point is given in the recent literature within the range of 2520 to 2570 C and the boiling point data range from 3900 to 4260 ± 160 C. Data on the heats of fusion, evaporation, sublimation, formation, and dissociation are reported. Also tabulated are enthalpy, temperature dependence of entropy, free energy of formation, coefficient of linear expansion, thermal shock resistance, breakage strength, modulus of elasticity as function of bulk weight, temperature dependence of heat conductivity, creep data, specific resistivity, properties of irradiated specimens, and crystalline parameters. Among the chemical properties reported are corrosive behavior, interaction with H<sub>2</sub>O, H<sub>2</sub>O<sub>2</sub>, SO<sub>2</sub>, S, Br, F, I, CS<sub>2</sub>, COCl<sub>2</sub>, CCl<sub>4</sub>, HF, HCl, and its behavior toward Pb, Mo, Ni, Nb, Ti, Zr, Be, Si, W, ThO<sub>2</sub>, ZrO<sub>2</sub>, UO<sub>2</sub>, and C at various temperatures. The phase diagrams of BeO with SiO<sub>2</sub>, ThO<sub>2</sub>, Al<sub>2</sub>O<sub>3</sub>, UO<sub>2</sub>, ZrO<sub>2</sub> are also discussed briefly. The toxicological properties of BeO are reviewed. 61 references.—NSA 21298

### 6.6.6, 6.3.10, 6.3.9, 3.5.3, 8.9.1

**High-Temperature Materials in Relation to the Satellite Re-Entry Problem.** P. Murray. (Symposium on) High-Altitude and Satellite Rockets, Cranfield, July, 1957, 1958, 82-88.

Possible materials for withstanding the high-temperature erosive conditions encountered during re-entry into the atmosphere are considered, including oxides and related refractories, molybdenum-0.45% titanium and Nimonic al-

loys, and flame-sprayed protective coatings. Use of massive insulation is also mentioned. It is considered necessary that the shell must be metallic.—MA. 19875

### 6.6.6, 3.5.9, 8.4.5

**Evaluation of Oxidation-Resistant Ceramics for High-Temperature Reactor Elements.** C. G. Harman, E. F. Ferrell, H. E. Wagner and J. F. Quirk. Battelle Memorial Inst. U. S. Atomic Energy Commission Pubn., BMI-787, December 1, 1952 (Declassified December 15, 1959), 39 pp. Available from Office of Technical Services, Washington, D. C.

Properties of 23 refractory oxidation-resistant ceramic compounds are tabulated. The thermal stresses and heat throughput capacities for nine of these compounds are estimated for conditions of steady heat flow and uniform heat generation at 1500 to 2500 F. The compounds studied have macroscopic thermal-neutron-absorption cross sections lower than 0.2 per centimeter. Data concerning the high-temperature stability of uranium compounds are tabulated for those with melting points above 2450 F. (auth)—NSA. 20104

### 6.6.6, 4.3.2, 4.3.3

**Corrosion Resistance of Borides of Columbium, Tantalum and Tungsten.** (In Ukrainian.) K. D. Modylevskaya and G. V. Samsonova. Ukrain. Khim. Zhur., Akademi Nauk Ukrain. (Ukrainian Chem. J.), 25, 55-61 (1959) Jan.

Borides of niobium tantalum and tungsten have a high resistance to acid and caustic soda corrosion at room temperature. 6 references.—RML. 18446

### 6.6.6, 3.4.9, 8.4.5

**An Evaluation of the Beryllia-Water Vapor Reaction in an Open-Cycle Air-Cooled Reactor.** R. L. McKisson. Atomic International Div., North American Aviation, Inc. J. Nuclear Materials, 1, 196-202 (1959) July.

An expression describing the corrosion rate of a beryllia surface in moist, flowing air has been developed and veri-



## TECHNICAL REPORTS on GENERAL CORROSION PROBLEMS

On sales to Texas addresses, add 2% tax.

**T-3A** Some Corrosion Inhibitors—A Reference List. A Report of T-3A on Corrosion Inhibitors. Publication 55-3. Per Copy \$1.50.

**T-3B** Bibliographies of Corrosion Products. Section One—A Report by NACE Technical Unit Committee T-3B on Corrosion Products. Publication No. 57-5. Per Copy \$3.25.

**T-3B** Bibliographies of Corrosion Products. Section Two—A Report of NACE Tech. Unit Committee T-3B on Corrosion Products. Pub. 57-21. Per Copy \$1.50.

**T-3B** Identification of Corrosion Products on Copper and Copper Alloys. A Report of NACE Tech. Unit Committee T-3B on Corrosion Products. Pub. 59-13. Per Copy \$1.50.

**T-3B** Bibliographies of Corrosion Products. Section Three—A Report of NACE Technical Unit Committee T-3B on Corrosion Products. Publication 60-4. Per Copy \$1.75.

**T-3B** The Analysis and Composition of Aluminum Corrosion Products. A Report of NACE Technical Unit Committee T-3B on Corrosion Products. Publication 60-5. Per Copy \$1.75.

**T-3C** Amount of Annual Purchases of Corrosion Resistant Materials by Various Industries—A Report of NACE Tech. Unit Comm. T-3C on Annual Losses Due to Corrosion. Pub. 59-8. Per Copy \$1.50.

**T-3E** Tentative Procedures for Preparing Tank Car Interiors for Lining. A Report by NACE Task Group T-3E-1 on Corrosion Control of Railroad Tank Cars. Per Copy \$1.50.

**T-3F** Symposium on Corrosion by High Purity Water: Introduction to Symposium on Corrosion by High Purity Water, by John F. Eckel; Corrosion of Structural Materials in High Purity Water, by A. H. Roebuck, C. R. Breden and S. Greenberg; Corrosion Engineering Problems in High Purity Water, by D. J. DePauli; The Importance of High Purity Water Data to Industrial Application, by W. Z. Friend. A Symposium sponsored by NACE Technical Unit Committee T-3F on Corrosion by High Purity Water. Per Copy \$3.75.

**T-3F** Symposium on Corrosion by High Purity Water. Five Contributions to the work of NACE Tech. Committee T-3F on High Purity Water. By A. A. Sugalski and S. L. Williams—Measurement of Corrosion Products in High Temperature, High Pressure Water Systems. By F. H. Krenz—Corrosion of Aluminum-Nickel Type Alloys in High Temperature Aqueous Service. By R. J. Lobsinger and J. M. Atwood—Corrosion of Aluminum in High Purity Water. By R. R. Dlesk—The Storage of High Purity Water. By D. E. Voyles and E. C. Fiss—Water Conditions for High Pressure Boilers. Pub. 57-22. Per Copy \$6.50.

**T-3F** Symposium on Corrosion by High Purity Water. Four Contributions to the Work of NACE Tech. Unit Comm. T-3F on High Purity Water. Pub. 58-13. Per Copy \$5.50.

Corrosion Behavior of Zirconium-Uranium Alloys in High Temperature Water by W. E. Berry and R. S. Peoples.

Corrosion and Water Purity Control for the Army Package Power Reactor by R. J. Clark and A. Louis Medin.

Removal of Corrosion Products from High Temperature, High Purity Water Systems With an Axial Bed Filter by R. E. Larson and S. L. Williams.

Some Relations Between Deposition and Corrosion Contamination in Low Make-Up Systems for Steam Power Plants by E. S. Johnson and H. Kehmna.

**T-3G-1** Cathodic Protection of Hulls and Related Parts. A Report of NACE Task Group T-3G-1 on Cathodic Protection of Hull Bottoms of Ships. Publication 60-7. Per Copy \$1.50.

**T-3G-3** Cathodic Protection of Process Equipment—A Report Prepared by NACE Task Group T-3G-3 on Cathodic Protection of Process Equipment. Pub. 59-9. Per Copy \$1.50.

**T-3H** Some Consideration in the Economics of Tanker Corrosion. A contribution to the work of Technical Committee T-3H on Tanker Corrosion by C. P. Dillon. Per Copy \$1.50.

Remittances must accompany all orders for literature the aggregate cost of which is less than \$5. Orders of value greater than \$5 will be invoiced if requested. Send orders to National Association of Corrosion Engineers, 1061 M & M Bldg., Houston, Texas. Add 75¢ per package to the prices given above for Book Post Registry to all addresses outside the United States, Canada and Mexico.

## NATIONAL ASSOCIATION OF CORROSION ENGINEERS

1061 M & M Bldg.

Houston 2, Texas



fied by experiment. The data support the hypothesis that the rate-controlling step in the corrosion process is the diffusion of the gaseous beryllium hydroxide product through the laminar boundary layer at the beryllia surface. The analysis, when used to predict the corrosion rates expected in the operation of an open-cycle, air-cooled, beryllia moderated power reactor, indicates that the corrosion reaction will not limit the feasibility of operation at beryllia surface temperatures below 860 °C. (auth) —NSA 20383

## 7. EQUIPMENT

### 7.4 Heat Exchangers

#### 7.4.1, 4.7

**Liquid-Metal Heat Exchangers.** R. A. Tidball. *Griscom-Russell Co. Power*, 104, No. 2, 82-85 (1960) Feb.

Design criteria for liquid-metal heat exchangers at ultra-high temperatures. Article deals with Na and NaK, information being abstracted from "Liquid Metals Handbook" published by Atomic Energy Commission and Navy Department. Important properties of heat-transfer fluids include melting point, specific heat, viscosity, density, thermal conductivity, and corrosion tendency. Corrosion of materials by Na and NaK depends on impurities such as O<sub>2</sub>, C, H<sub>2</sub>, Ca and N<sub>2</sub> that liquid metals may contain. O<sub>2</sub> is most important impurity. Materials suitable for liquid-metal exchangers include C steel, Cr-Fe alloys, Cr-Fe-Mo alloys, austenitic stainless steels, Ni and high-Ni alloys and super-alloys

over various temperature ranges. Factors in construction-materials selection include resistance to thermal shock, creep and rupture properties, corrosion, availability of shapes, and fabricating difficulty. Preheating of heat exchangers, maintenance, prevention of leakage, fabrication techniques, and inspection are considered. Graphs, diagram of reactor system using two fluid loops with an intermediate heat exchanger.—INCO. 20183

#### 7.4.1, 6.2.5, 6.2.3, 3.2.2, 8.4.5

**Loop Testing of Stainless Steel and Bimetallic Model Heat Exchangers.** ERDL-Task 1, Phase 1. Martin Co. July, 1959, 92 pp. Contract DA-44-009-ENG-3043. Martin Co. Nuclear Div., Baltimore, Maryland.

Two sets of model configuration heat exchangers were dynamically tested with selected secondary water conditions in a high pressure water loop. Each set of the test units consisted of a steam generator and a superheater. One set was fabricated entirely of stainless steel, the other set was of bimetal construction with a stainless steel primary, and a low carbon steel secondary. A bimetal miniature heat exchanger, fabricated with the same configuration as the full-size models, was subjected to a static corrosion test in a loop bypass test section. The low carbon steel secondary water systems of the bimetal steam generator and superheater suffered considerable general corrosion and pitting. Severe cracking of the tube sheet and shell and the shell adjacent to the tube sheet caused the failure of the type 304 stainless steel superheater. Cracking was not found in the secondary side of any of the other four test vessels. Cracking resulting from fabrication of the tubing were found on the primary side of the miniature unit.—NSA. 19829

### 7.5 Containers

#### 7.5.2, 5.4.5

**Overcoming Can Corrosion in Water Emulsion Paints.** L. E. Kneeland and C. S. Stephens. *Am. Paint J.*, 44, No. 2, 21-40 (1959).

Cans are manufactured from electrolytic or hot-dipped tin plate or occasionally fromterne plate. They may be subsequently coated with phenolic or epoxy resin coatings or combined epoxy/phenolic systems. The particular problems associated with styrene/butadiene, acrylic and polyvinyl acetate latex paints, the first two named being alkaline and the last acid, are considered, and the most satisfactory systems are indicated.—RPI. 19791

#### 7.5.1, 6.4.2, 8.3.5, 5.4.2, 5.4.5

**Aluminum Containers.** J. Jackson. American Can Company. Paper before Chemical Specialties Mfgs. Assoc., 46th Annual Mtg., Washington, D. C., Dec. 9, 1959. *Soap and Chemical Specialties*, 36, No. 3, 119-120, 123, 195-196 (1960) March.

Advantages and disadvantages of extruded aluminum aerosol containers are listed. One problem is fact that aluminum is less corrosion resistant than tinplate for most products, and thus requires high quality protective coatings. Although proper formulation of product and propellant mixture may minimize corrosion attack on aluminum, there are relatively few products that can be packed

successfully in an aluminum container, interior walls of which are not coated. Studies showing effect of composition of aluminum alloy on its corrosion resistance are discussed. Graphs show effect of magnesium content on corrosion of enameled aluminum cans by tomato juice and pears, and effect of magnesium content on corrosion of plain and enameled aluminum cans by asparagus. Anodizing treatment substantially increases corrosion resistance of aluminum but cost is high. Some form of chemical treatment before application of coating is favored by a number of workers, but studies made in Canco Lab. have indicated that properly formulated enamels will perform satisfactorily on cleaned aluminum surfaces without elaborate chemical treatments. Epoxy and phenolic resin types of enamels and vinyl top coats have shown merit. Other related types of polymers are under study. Sketches of impact extrusion process. 6 references.—INCO. 20056

### 7.6 Unit Process Equipment

#### 7.6.6, 8.5.3, 6.2.3

**Digester Corrosion Experience at Union Bag Camp Paper Corp.** H. B. Harris and L. H. Park. *Tappi*, 43, 226A-228A (1960) May.

Corrosion resistance and corrosion rates of sulfate digesters made from ASME S1, A 70, A 285 and A 212 carbon steel. Corrosion rates of A 212 steel digesters clad with Inconel, with 316 columbium stabilized steel and with carbon brick lining. Control of local area corrosion with applications of 310 stainless steel welded overlay. Method of operation of the digesters to produce kraft pulp.—RML. 20651

#### 7.6.5, 4.3.2, 1.3, 5.4.2, 5.3.2


**Taming Phosphoric Acid Evaporators.** R. C. Bennett. Swenson Evaporator Co. Chem. Processing, 23, No. 7, 123-125 (1960) July.

Reviews latest advances. Basic vessel construction is now either Pb-lined or rubber-lined if operation is within 160-180 °F. Pb-lined fabrication is required for higher temperatures. Agitator-equipped tank mounted below evaporator removes precipitated impurities from recirculating liquor, minimizing scale and salt deposition inside evaporator components. Evaporators can concentrate H<sub>3</sub>PO<sub>4</sub> continuously for 60-70 hours. Other details are described.—INCO. 21130

#### 7.6.4, 4.7, 3.5.2, 4.2.3

**Corrosion of Superheaters and Reheaters of Pulverized-Coal-Fired Boilers.** W. Nelson and C. Cain, Jr. Paper before Am. Soc. Mech. Engrs., Annual Meeting, Atlantic City, Nov. 29-Dec. 4, 1959. *J. Eng. for Power* (Trans. Am. Soc. Mech. Engrs.), 82, Series A, No. 3, 194-201; disc., 201-204 (1960) July.

Laboratory work shows that molten complex Fe and/or Al alkali sulfates formed in fireside deposits of boilers having steam temperatures above about 950 °F are responsible for corrosion of superheater and reheater tubes of steels T22 (2¼ Cr-1 Mo) and Type 321. Corrosion is a chemical reaction in which tube metal reacts with molten sulfates to give Fe oxide and sulfide. Since it starts at temperatures below oxidation (scaling) temperature limit for alloys used in these sections of a boiler, gas-phase scaling-temperature limits cannot be



**CONTROL OF  
PIPELINE CORROSION**

This 61-page, 6 by 9-inch booklet is now in its fourth printing. Written by O. C. Mudd, formerly chief corrosion engineer for Shell Pipe Line Corp., it contains much of the basic information and common sense instruction needed to plan and execute cathodic protection systems on underground plant.

On sales to Texas addresses, add 2% tax.

**Per Copy, postpaid . . . . . \$1.25**  
**5 or more copies, each . . . . . \$1.00**

Remittances must accompany all orders for literature the aggregate cost of which is less than \$5. Orders of value greater than \$5 will be invoiced if requested. Send orders to National Association of Corrosion Engineers, 1061 M & M Bldg., Houston, Texas. Add 75¢ per package to the prices given above for Book Post Registry to all addresses outside the United States, Canada and Mexico.

**NATIONAL ASSOCIATION  
OF CORROSION ENGINEERS**  
 1061 M & M Bldg.      Houston 2, Texas



used to judge suitability of a given alloy for service in an area subject to liquid-phase corrosion by complex sulfates of an ash deposit. Studies to find more corrosion-resistant alloys or less corrosion-producing coals seem promising fields for future effort. However, no practical alloy has yet been found which offers consistently better resistance than Type 321 in this service. Shielding lead tubes in deposit-forming area of finishing reheater and superheater where skin-metal temperatures are 950-1300 F is best practical means to date for preventing accelerated liquid-phase corrosion. Type 304 is satisfactory for this application. Illustrations, 5 references.—INCO. 21468

#### 7.6.4, 4.2.3, 3.5.9

**Some Results of the Investigation of the Corrosion of Air Preheaters in a Flue Gas Medium.** (In Russian.) Iu. G. Dashkev. *Izvestiia Vysshikh Uchebnykh Zavedenii, Energetika*, No. 4, 91-99 (1960) April.

The region of maximum corrosion damage in air preheater pipes during layer combustion of anthracite AM is observed in the case of a surface temperature lower than the dew point at 35-45 C. The zone of low corrosion speed in the region of temperature lower than the dew point is small (at  $K = 0.2$  min/yr—it extends within the range of temperature  $t$  ( $H_2O + 30 C \div 85 C$ ) and its position varies.—BTR. 20586

## 8. INDUSTRIES

### 8.10 Group 10

#### 8.10.2, 6.3.17, 8.4.5, 4.3.2

**Corrosion Problems in Processing Nuclear Fuels.** W. G. O'Driscoll and T. E. Evans. *Ind. Chemist*, 34, No. 405, 585-588 (1958).

Extraction and purification of uranium is carried out in plant of conventional design: in the solvent-extraction process the stainless-steel plant is subject to very little corrosion; in the dryway process, involving treatment of uranium dioxide with hydrofluoric acid, corrosion is prevented by use of platinum linings where exhaust gases condense. Spent fuel elements are stored in cooling ponds to allow decay; corrosion of the magnesium casing is prevented by keeping the water at pH 11. Dissolution of fuel elements in nitric acid before separation of plutonium is carried out in a special stainless-steel container. The effect of various redox systems on corrosion and future problems are considered.—MA. 18173

#### 8.10.2, 6.2.3, 6.2.5, 3.2.2, 4.3.2

**Corrosion of Mild Steel and Stainless Steel Type 316L in Concentrated Sulfate-Carbonate-Bicarbonate-Chloride Solutions Approaching Those Used in Grinding and Leaching Uranium Ore.** I. I. Tingley and R. R. Rogers. *Trans. Can. Inst. Mining & Met.*, 63, 16-21 (1960). *Can. Mining & Met. Bull.*, 53, No. 573, 18-23 (1960) Jan.

Panels of mild SAE 1025 steel (0.22-0.28 C), and of Type 316L were used in laboratory investigation. Some panels were partially immersed and others totally immersed latter being vertical in some cases and horizontal in others. Other panels were L-shaped, with vertical part partially immersed. Results of

tests on mild steel panels are considered in detail. No corrosion of stainless steel occurred under any experimental conditions. Mechanism by which severe pitting corrosion took place at plant is described. Experiments show that pitting corrosion of this particular type may be prevented by: using a sufficiently low sulfate content in solution, using a sufficiently high pH in solution, preventing formation of solid deposits on metal surface, preventing formation of oxygen concentration cells by eliminating aeration of solution or by other means, and using Type 316L instead of ordinary mild steel. Numerous tables, photos of specimens.—INCO. 19951

#### 8.10.3, 7.2, 5.4.5, 6.6.11

**Pipeline Transportation of Concentrates.** D. A. Fraser. *Inco of Canada. Mining Congr. J.*, 46, No. 3, 44-48 (1960) Mar.

Erection of system for pumping 1800 tpd of Cu-Ni sulfide concentrates 7½ miles (from Inco's Creighton mill to Copper Cliff concentrator) was result of elaborate test work to determine correct pipe size, pumping station spacing and power requirements. Eight-in. wood stave pipe was size required for installation. On pipeline trestle are two 13-in. tailing pipes and two 8-in. concentrate pipes (second pipe in each case is a standby). There is also a 6-in. wood stave line for water supply. Three sizes of pipes are of wire wound, wood stave

construction with banded couplings. Finished pipes are asphalt coated to prevent corrosion of wire winding and to further protect wood. Pumping system and its operation are described.—INCO. 21330

#### 8.10.2, 6.3.19

**Production of Zinc and Zinc-Lead Alloy Strip by Powder-Metallurgy Methods.** H. Weik, G. Ogiemann and R. Ergang. *Metall*, 13, No. 5, 398-404 (1959).

Experiments on Zn-Pb powder mixtures containing 0-10% Pb showed that blocks suitable for rolling can be pressed at 200 C. Using rolls up to 400 mm in diameter, powder mixtures can be rolled directly into ~1.3 mm thick strip of satisfactory properties without sintering. Elevated powder temperature and finer grading improve properties, provided that no noticeable oxidation is induced. Properties are improved on subsequent rolling and reach those of cast and rolled alloys except for the low (1-19%) elongation. Small Pb content was beneficial, probably because it lowered porosity, but impaired mechanical properties in higher (>1%) concentration. Surprisingly, the corrosion-resistance of sintered material containing 1-5% Pb was better than that of materials produced from the melt, but it was poor with lower or higher Pb contents. 22 references, 10 figures, 11 illustrations.—MA. 20320



## TECHNICAL REPORTS on PROTECTIVE COATINGS

### Other Than Pipe Line Coatings

On sales to Texas addresses, add 2% tax.

**T-6A Application Techniques, Physical Characteristics and Corrosion Resistance of Polyvinyl Chloride-Acetates.** A Report of Unit Committee T-6A on Organic Coatings and Linings for Resistance to Chemical Corrosion. Publication 54-4. Per Copy \$1.50.

**T-6A Report on Rigid Polyvinyl Chloride.** A Report of NACE Technical Unit Committee T-6A on Organic Coatings and Linings for Resistance to Chemical Corrosion. Publication 56-4. Per Copy \$1.50.

**T-6A Report on Epoxy Resins.** A Report of NACE Technical Unit Committee T-6A on Organic Coatings and Linings for Resistance to Chemical Corrosion. Publication 56-5. Per Copy \$1.50.

**T-6A Report on Application Techniques, Physical Properties and Chemical Resistance of Chlorinated Rubber Coatings.** NACE Technical Unit Committee T-6A on Organic Coatings and Linings for Resistance to Chemical Corrosion. (Pub. 56-6.) Per Copy, \$1.50.

**T-6A Vinylidene Chloride Resins.** A Report of Unit Committee T-6A Prepared by Task Group T-6A-3 on Vinylidene Chloride Polymers. Publication No. 57-9. Per Copy \$1.50.

**T-6A Reinforced (Faced) Tank Linings.** A Report by NACE Committee T-6A. Pub. 58-7. Per Copy \$1.50.

**T-6A Report on Thermoplastic Coal Tar Base Linings.** A Report of NACE Unit Committee T-6A on Organic Coatings and Linings for Resistance to Chemical Corrosion, prepared by Task Group T-6A-16 on Coal Tar Coatings. Pub. 58-10. Per Copy \$1.50.

**T-6A-5 Application Techniques, Properties and Chemical Resistance of Polyethylene Coatings—A Report of NACE Task Group T-6A-5 on Polyethylene.** Pub. 59-7. Per Copy \$1.50.

**T-6B Protective Coatings for Atmospheric Use: Their Surface Preparation and Application Physical Characteristics and Resistance.** A Report of Unit Committee T-6B on Protective Coatings for Resistance to Atmospheric Corrosion. Publication No. 57-10. Per Copy \$2.75.

**T-6D-2 Specification Format for Surface Preparation and Material Application For Industrial Maintenance Painting—A Report of NACE Technical Unit Committee T-6D on Industrial Maintenance Painting.** Prepared by Task Group T-6D-2 on Standardization of Scope of Painting Specifications. Publication 61-1. Per Copy \$1.50.

**T-6D-3 Industrial Maintenance Painting Program.** A Report of NACE Technical Unit Committee T-6D on Industrial Maintenance Painting, Prepared by Task Group T-6D-3 on Paint Programs. Publication 60-8. Per Copy \$1.50.

**T-6E Protective Coatings in Petroleum Production—A Report of NACE Technical Unit Committee T-6E on Protective Coatings in Petroleum Production.** Publication 61-2. Single Copy \$2.00.

2-4 Copies 1.50 each  
5-10 Copies 1.00 each  
Over Ten Copies—Special Quote

**TP-6G First Interim Report on Recommended Practices for Surface Preparation of Steel.** (Pub. 50-5). Per Copy, \$1.75.

**TP-6G Second Interim Report on Surface Preparation of Steels for Organic and Other Coatings.** (Pub. 53-1.) Per Copy, \$3.25.

**T-6H Glass Linings and Vitreous Enamels—A Report of NACE Technical Unit Committee T-6H on Glass Linings and Vitreous Enamels.** Publication 60-16. Per Copy \$1.75.

**T-6K Acid Proof-Vessel Construction with Membrane and Brick Linings.** A Report of NACE Technical Unit Committee T-6K on Corrosion Resistant Construction with Masonry and Allied Materials. Publication No. 57-6. Per Copy \$2.75.

**T-6K Acidproof Floor Construction With Membrane and Brick.** A Report of NACE Technical Unit Committee T-6K on Corrosion Resistant Construction With Masonry and Allied Materials. Publication 60-1. Per Copy \$1.50.

Remittances must accompany all orders for literature the aggregate cost of which is less than \$5. Orders of value greater than \$5 will be invoiced if requested. Send orders to National Association of Corrosion Engineers, 1061 M & M Bldg., Houston, Texas. Add 75¢ per package to the prices given above for Book Post Registry to all addresses outside the United States, Canada and Mexico.

## NATIONAL ASSOCIATION OF CORROSION ENGINEERS

1061 M & M Bldg.

Houston 2, Texas





# NATIONAL ASSOCIATION of CORROSION ENGINEERS

Executive Offices: 1061 M & M Bldg., Houston 2, Texas  
Telephone CAPITOL 4-6108

Executive Secretary.....T. J. HULL  
Assistant Secretary and Exhibition Manager.....R. W. HUFF, JR.  
Technical Committee Secretary.....J. F. VANDER HENST, JR.  
Publication Director.....NORMAN E. HAMNER  
Editorial Assistant.....DALE MILLER

Inquiries regarding membership, and all general correspondence should be directed to the Executive Secretary at the administrative headquarters of the National Association of Corrosion Engineers, 1061 M & M Building, No. 1 Main Street, Houston 2, Texas.

The National Association of Corrosion Engineers is a non-profit, scientific and research association of individuals and companies concerned with corrosion or interested in it, whose objects are:

- (a) To promote the prevention of corrosion, thereby curtailing economic waste and conserving natural resources.
- (b) To provide forums and media through which experiences with corrosion and its prevention may be reported, discussed and published for the common good.
- (c) To encourage special study and research to determine the fundamental causes of corrosion, and to develop new or improved techniques for its prevention.
- (d) To correlate study and research on corrosion problems among technical associations to reduce duplication and increase efficiency.
- (e) To promote standardization of terminology, techniques, equipment and design in corrosion control.
- (f) To contribute to industrial and public safety by promoting the prevention of corrosion as a cause of accidents.
- (g) To foster cooperation between individual operators of metallic plant and structures in the joint solution of common corrosion problems.
- (h) To invite a wide diversity of memberships, thereby insuring reciprocal benefits between industries and governmental groups as well as between individuals and corporations.

It is an incorporated association without capital stock, chartered under the laws of Texas. Its affairs are governed by a Board of Directors, elected by the general membership. Officers and elected directors are nominated by a nominating committee in accordance with the articles of organization. Election is by the membership.

## Advertising and Editorial Offices of CORROSION

Address all correspondence concerning advertising, circulation and editorial matters relating to CORROSION to the NACE executive offices, 1061 M & M Building, Houston 2, Texas. Inquiries concerning and orders for reprints of technical information published in CORROSION should be sent to this address also.

## OFFICERS and DIRECTORS

### OFFICERS

President.....EDWARD C. GRECO  
United Gas Corporation,  
Shreveport, La.  
Vice President.....R. McFARLAND, JR.  
Hills-McCanna Company,  
Chicago, Ill.  
Treasurer.....C. G. GRIBBLE, JR.  
Metal Goods Corporation,  
Houston, Texas  
Executive Secretary.....T. J. HULL  
1061 M & M Bldg., Houston, Texas

### DIRECTORS

#### Past-President

GEORGE E. BEST.....1961-62  
Manufacturing Chemists' Assoc., Inc.,  
Washington, D. C.

#### Representing Active Membership

F. E. KULMAN.....1961-64  
Consolidated Edison Company of New York,  
Inc., New York City, N. Y.  
T. J. MAITLAND.....1960-63  
American Telephone & Telegraph Company,  
New York, N. Y.  
J. P. BARRETT.....1959-62  
Pan American Petroleum Corp., Tulsa, Okla.  
E. L. SIMONS.....1959-62  
General Electric Co., Schenectady, N. Y.

#### Representing Corporate Membership

L. W. GLECKMAN.....1961-64  
Wyandotte Chemicals Corporation,  
Wyandotte, Mich.  
F. D. STULL.....1961-64  
Texas Gas Transmission Corporation,  
Owensboro, Ky.  
J. E. RENCH.....1960-63  
Napko Corporation, Houston, Texas  
J. S. DORSEY.....1960-63  
Southern California Gas Co., Los Angeles, Cal.  
GUY F. WILLIAMS.....1959-62  
Dowell Incorporated, Tulsa, Okla.

#### Representing Regional Divisions

E. F. BLADHOLM.....(Western) 1961-64  
Southern California Edison Company,  
Los Angeles, Cal.  
A. B. SMITH.....(Southeast) 1960-63  
Amercoat Corp., Jacksonville, Fla.  
J. D. BIRD.....(Northeast) 1960-63  
The Dampney Company, Hyde Park,  
Boston, Mass.  
E. F. MOORMAN.....(North Central) 1959-62  
International Harvester Co., Chicago, Ill.  
J. A. CALDWELL.....(South Central) 1959-62  
Humble Oil & Refining Co., Houston, Texas  
T. R. B. WATSON.....(Canadian) 1959-62  
Corrosion Service Limited, Toronto, Ont., Canada

#### Directors Ex Office

W. F. FAIR, Chairman Regional  
Management Committee  
Tar Products Division, Koppers, Inc.,  
Verona, Pa.  
R. A. BRANNON, Chairman Policy and Planning  
Committee  
Humble Pipe Line Co., Houston, Texas  
R. S. TRESEDER, Chairman Publications  
Committee  
Shell Development Co., Emeryville, Cal.  
J. L. BATTLE, Chairman Technical Practices Com-  
mittee  
Humble Oil & Refining Co., Houston, Texas



## Topic of the Month

# Detection of Interference Current on a Simulated Pipe Line\*

By J. M. TAYLOR, JR.\* and J. P. BARRETT\*

## Introduction

THE WIDESPREAD application of cathodic protection to oil field structures has created considerable interest in attendant problems of interference on flow lines and well casings. Accordingly, laboratory tests were conducted to find some of the limits of detection of interference current on a simulated pipe line by the measurement of the IR drop produced. It is realized that, while the results of this work are not new to those experienced in this area, they may well be startling to some new workers faced with the problem of determining interference in the field.

## Procedure

A straight piece of wire was suspended horizontally between two insulators. One foot of the wire had approximately the same resistance as 200 feet of two-inch, 3.65-pound pipe.

A diagram of the electrical circuit is shown in Figure 1. Points A, B, C, D, E, and F represent contacts made on the wire with clip leads. Points B and C represent areas of exit and entry of interference current on this simulated pipe, while E and F are points through which "long line" current was impressed. Points A and D represent contacts made with metallic probes used in measurement of IR drop along the "pipe". The potentiometer used for these measurements was adjusted so that the smallest scale division represented 0.05 millivolt. Thus the sensitivity of this voltage measuring device was equal to, or greater than, that of instruments commonly used in the field.

## Results and Discussion

Results of five experiments are shown in Tables 1 through 5. With the exception in Experiment No. 4, the section of "pipe" carrying interference current (between B and C) was centered between the probes A and D. In Nos. 1 and 2, the interference current flowed through two different lengths of "pipe". Interference current and "long line" current flowed in the same and then in opposite directions in No. 3. Position of the probes was varied in No. 4, with probe separation

having been held constant while traversing the affected area. In No. 5, the spacing of the probes A and D was varied.

The data in the first two experiments conformed with Ohm's Law within experimental error, as would be expected, and calculated resistances corresponded with relative lengths of affected "pipe". The minimum detectable current on 25-50 feet of "pipe" was between 40 and 160 milliamperes, with 70 milliamperes being indicated if the data are interpolated conservatively.

In the third experiment a "long line" current of 280 milliamperes was used. The minimum detectable interference current flowing to a 25-foot section of "pipe" was between 70 and 165 milliamperes. When the interference current was in the same direction as the long line current, the IR drop between the points A and D was increased, and vice versa, as would be expected.

## Abstract

Laboratory tests were made to determine some of the limits of detection of interference current on a simulated pipe line. Tests involved measurement of the IR drop produced on a straight piece of wire suspended horizontally between two insulators. It was found that the minimum detectable current on 25-50 feet of "pipe" carrying no long line current was between 40 and 160 ma, and the minimum on 25 feet of "pipe" already carrying a long line current of 280 ma was between 70 and 165 ma. The detectability of 160 ma interference current on 25 feet of "pipe" was unaltered when spacing between probes was changed from "25 feet" to "600 feet," so long as the affected section was kept between the probes. In cases where only a part of the affected section of pipe was included in a survey, it was found the IR drop observed could be so low that erroneous conclusion might be reached that no interference was present.

2.3.5

In the fourth experiment an interference current of 160 milliamperes was flowing on 25 feet of "pipe", and a survey was made across the affected section with a "200-foot" spacing between the

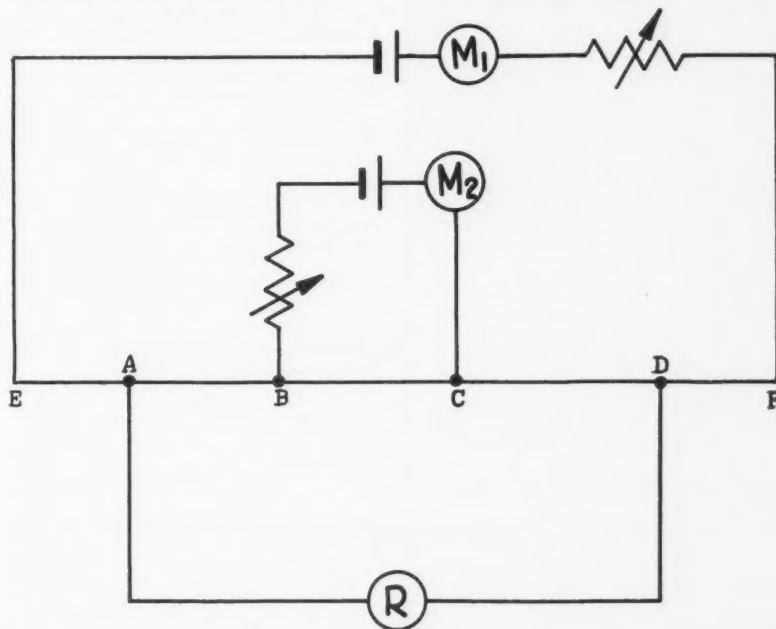


Figure 1—Electrical circuit for study of interference. Legend: R = potentiometer; M<sub>1</sub> and M<sub>2</sub> = milliammeters; A and D = movable contacts ("probes") to measuring circuit; B and C = movable contacts to interference current source; E and F = movable contacts to long-line current source.

\* Submitted for publication May 24, 1961.

\* Pan American Petroleum Corp., Tulsa, Oklahoma.



**TABLE 1—Variation of IR Drop with Interference Current—Affected Section Centered between Probes\***

Interference Current Between B and C, ma.	Millivolts Between A and D	$R = \frac{E}{I}$ , ohms
40.....	..**	.....
160.....	0.42	0.0026
230.....	0.55	0.0024
320.....	0.85	0.0027
620 ± 5.....	1.64	0.0026

**\* Conditions:**

Distance between A and D = 1 ft., equivalent to 200 ft. of pipe.  
 Distance between A and B =  $4\frac{1}{4}$  in., equivalent to 75 ft. of pipe.  
 Distance between B and C = 3 in., equivalent to 50 ft. of pipe.

\*\* This value was below the sensitivity of the instrument.

**TABLE 2—Variation of IR Drop with Interference Current—Affected Section Centered between Probes\***

Interference Current Between B and C, ma.	Millivolts Between A and D	$R = \frac{E}{I}$ , ohms
40.....	..**	.....
70.....	0.07	0.0010
95.....	0.10	0.0011
160.....	0.20	0.0012
310.....	0.38	0.0012

**\* Conditions:**

Distance between A and D = 1 ft., equivalent to 200 ft. of pipe.  
 Distance between A and B =  $5\frac{1}{4}$  in., equivalent to 87.5 ft. of pipe.  
 Distance between B and C =  $1\frac{1}{2}$  in., equivalent to 25 ft. of pipe.

\*\* This value was below the sensitivity of the instrument.

probes. The IR drop measurement did not change until (1) one of the probes fell within the affected area, or (2) both probes fell to one side of the affected area. This illustrates that, unless a thorough survey is made, a section of pipe affected by interference might be missed. Furthermore, if only a part of the affected section is included in the survey, the readings might be so low as to lead to the erroneous conclusion that no interference is present.

In the fifth experiment an interference current of 160 milliamperes was flowing on 25 feet of "pipe", and the spacing of the probes was varied from "25 feet" to "600 feet". The IR drop was essentially unchanged, indicating that the spacing was not important so long as the affected section was kept between the probes. The

**TABLE 3—Variation of IR Drop with Interference Current and "Long Line" Current in Same and Opposite Directions—Affected Section Centered between Probes\***

Long Line Current in the Direction E to F, ma.	Interference Current Added to Long Line Current, ma.**	Interference Current Opposed to Long Line Current, ma.**	Millivolts Between A and D
280.....	0	...	3.00
280.....	70	...	3.00
280.....	165	...	3.10
280.....	315	...	3.32
280.....	...	210	2.64
280.....	...	165	2.72

**\* Conditions:**

Distance between A and D = 1 ft., equivalent to 200 ft. of pipe.  
 Distance between A and B =  $5\frac{1}{4}$  in., equivalent to 87.5 ft. of pipe.  
 Distance between B and C =  $1\frac{1}{2}$  in., equivalent to 25 ft. of pipe.

\*\* Actually, only the current sources were added or opposed, with a resultant current in only one direction along "pipe".

same test leads were used for all five experiments, making the resistance of the external circuits constant. Duplicate readings were observed to verify results.

In these experiments, a wire was used to simulate a single pipe line under ideal conditions for detection of current. When a pipe is buried in the soil, however, the situation becomes more complex. The results of the present study show that, before the field man makes an interpretation of his results and declaration of the extent of interference, he should be familiar with the limits of his instruments and survey methods.

**Conclusions**

1. Some of the limits of detection with a potentiometer of interference current on a simulated two-inch, 3.65-pound pipe line with the affected section entirely between the probes were: (a.) The minimum on 25-50 feet of "pipe" carrying no long line current was between 40 and 160 milliamperes and estimated at 70 milliamperes. (b.) The minimum on 25 feet of "pipe" already carrying a long line current of 280 milliamperes was between 70 and 165 milliamperes.

2. The detectability (with the above potentiometer) of 160 milliamperes interference current on 25 feet of "pipe"

**TABLE 4—Variation of IR Drop with Position of Probe A—Separation of Probes Held Constant While Traversing Affected Section\***

Distance** Between A and B, Inches	Millivolts Between A and D	Remarks
+11	0.12	Probe D between B and C
+9	0.20	B and C between probes A and D
+ $5\frac{1}{4}$	0.24 }	B and C between probes A and D
+4	0.20 }	B and C between probes A and D
+2	0.20	B and C between probes A and D
+ $\frac{1}{2}$	0.20	B and C between probes A and D
— $\frac{1}{2}$	0.10	Probe A between B and C
— $1\frac{1}{4}$	0.02	Probe A between B and C
—2	0.00	Probes A and D to the right of B and C

**\* Conditions:**

Distance between A and D = 1 ft., equivalent to 200 ft. of pipe.  
 Distance between B and C =  $1\frac{1}{2}$  in., equivalent to 25 ft. of pipe.  
 Distance between A and B varied.  
 Interference Current between B and C = 160 ma.

\*\* The plus sign means that point A was to the left of point B.  
 The minus sign means that point A was to the right of point B.

**TABLE 5—Variation of IR Drop with Spacing of Probes—Affected Section Approximately Centered between Probes\***

Distance Between A and D, In.	Distance Between A and B, In.	Millivolts Between A and D
$1\frac{1}{2}$ .....	0	0.23
$2\frac{1}{4}$ .....	$\frac{1}{4}$	0.22
36.....	14	0.22

**\* Conditions:**

Distance between B and C =  $1\frac{1}{2}$  in., equivalent to 25 ft. of pipe.  
 Distance between A and D (and thus between A and B) varied.  
 Interference Current between B and C = 160 ma.

was unaltered when the spacing between probes was changed from "25 feet" to "600 feet", so long as the affected section was kept between the probes.

3. If only a part of the affected section of pipe is included in a survey, the IR drop observed might be so low as to lead to the erroneous conclusion that no interference is present.

4. Interference on a buried pipe might be missed if there is a lack of instrument sensitivity or a lack of thoroughness in conducting the survey.

Any discussion of this article not published above will appear in June, 1962 issue



# Sulfide Stress Cracking of Steels For API Grade N-80 Tubular Products\*

By M. F. BALDY

## Introduction

**D**URING THE past decade there have been many investigations into the effects of aqueous hydrogen sulfide environments on steel. These have been prompted by failures of tubing and well equipment in high pressure sour condensate wells. Failure is attributed to sulfide stress cracking which results in fracture of the steel when it is subjected to a critical stress and exposure in moist or aqueous hydrogen sulfide. The work of Schuetz and Robertson,<sup>1</sup> and others, indicates that failure under these conditions is due primarily to embrittlement of the metal by hydrogen released during corrosion by hydrogen sulfide.

The work presented in this paper is part of an investigation to measure the effects of production and environmental variables on the susceptibility of tubing and casing steels to sulfide stress cracking. Earlier investigations<sup>2</sup> and field experience have indicated that little difficulty is encountered with tubing in sour condensate wells when API Grade J-55 is employed. When N-80 and higher strength grades are used, the susceptibility to cracking is increased.

The primary aim of this work was the development of an N-80 grade tubing which had improved resistance to sulfide stress cracking. It had been determined in previous work in this investigation that sufficient tempering, or over-aging in the case of precipitation hardening alloys, or an isothermal transformation after austenitizing increased the resistance of various steels to sulfide stress cracking. These results are in agreement with those obtained by Bloom,<sup>3</sup> Fraser and Treseder,<sup>4</sup> and Vollmer.<sup>5</sup> It was determined that these treatments also decreased the possibility of failure after cold work and exposure to hydrogen sulfide. Tempering the C-Mn-Mo grade of N-80<sup>(1)</sup> tubing after normalizing appeared to offer a solution to this problem. Measurements of the tensile properties of normalized and tempered N-80 indicated that 80,000 psi min. yield strength could not be maintained with certainty if the material was properly tempered. An experimental alloy<sup>(2)</sup> was, therefore, developed to meet

## Abstract

A laboratory investigation was made of various factors affecting the sulfide stress cracking resistance of a C-Mn-Mo grade of steel commonly used for producing API Standard 5A, Grade N-80 tubular products. It was found that the sensitivity to sulfide stress cracking of this steel in the normalized condition was increased significantly by 1 percent plastic prestrain. Experiments with the same material in the normalized and tempered condition indicated that tempering decreased the effect of subsequent cold work on sulfide stress cracking. Specimens tempered at 1150 F had somewhat greater resistance to failure than those tempered at 1200 F. The corrosion rate of this C-Mn-Mo steel in the acidified sulfide solution used for testing was independent of applied stress and prior thermal or mechanical history. An experimental C-Mn-Mo-V low alloy steel capable of meeting API 5A Grade N-80 requirements was developed for use in sulfide wells. The laboratory results obtained suggest that the sulfide stress cracking resistance of this new steel is superior to that of the normalized and tempered C-Mn-Mo steel.

80,000 psi minimum yield strength, or higher values, and in addition to have increased resistance to sulfide stress cracking.

The work presented in this paper is a comparison of the sulfide stress cracking resistance of C-Mn-Mo N-80 steel in the normalized condition, and also after tempering, with an experimental alloy having an 80,000 psi minimum yield strength.

## Materials and Test Procedure

Sections of 2 7/8-inch OD x 0.217-inch wall tubing from two heats of N-80 steel were used in this investigation. Two laboratory induction heats of the experimental analysis were also tested. The first of these experimental heats (No. 1032) was a 15-lb. heat cast into a 2-inch square ingot and then press forged to a 1-inch square bar. The second induction heat (No. L5061) was a 100-lb. heat cast into tapered 4-inch square, 35-lb. ingots. Ingot A of this second heat was direct rolled to a 1 1/2-inch thick plate approximately 4 inches wide, and Ingot B was press forged to a 1 1/2-inch square bar. The chemical analyses of the tubes and induction samples are shown in Table 1. The heat treatments and tensile properties of the materials tested are in Table 2. The experimental analysis, a C-Mn-Mo-V material, was heat treated in the form of 1/2 inch square x 5 inch long longitudinal blanks.

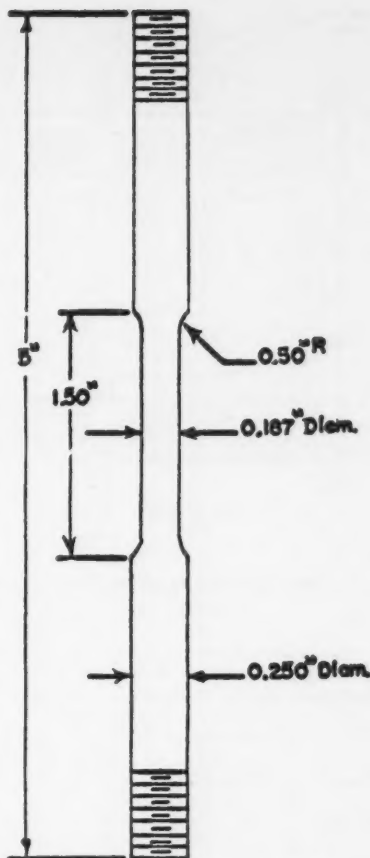


Figure 1—Tensile corrosion test specimen.



About  
the  
Author

M. F. BALDY is Research Metallurgical Engineer with the National Tube Division Research Laboratory, United States Steel Corporation, Pittsburgh, Pa. He received a BS in Metallurgical Engineering from Carnegie Institute of Technology in 1948. Since 1952, he has been associated with National Tube Division where his work is principally in the field of physical metallurgy and notch toughness studies of steels used for high strength steel tubular products. He is a member of the American Society for Metals.

\* Submitted for publication March 27, 1961. A paper presented at the 17th Annual Conference, National Association of Corrosion Engineers, Buffalo, New York, March 13-17, 1961.

(1) The nominal analysis of this material is 0.42 C, 1.50 Mn, 0.040 Max. P and S, 0.18 Si, and 0.18 Mo. The standard heat treatment for this material is normalizing. In the balance of this paper any reference to N-80 tubing, or tests therefrom, implies specifically the above-mentioned alloy. Any heat treatment other than the standard normalize will be so stated.

(2) The nominal analysis of this material is 0.24 C, 1.15 Mn, 0.040 Max. P and S, 0.15 Si, 0.45 Mo, 0.10 V. This material is heat treated by normalizing and tempering.

TABLE 1—Chemical Analysis of Steels Used in Sulfide Stress Cracking Tests

Grade	Heat	Element, Percent By Weight						
		C	Mn	P	S	Si	Mo	V
N-80	7591	0.44	1.66	0.013	0.026	0.26	0.24	....
N-80	6538	0.46	1.62	0.014	0.025	0.23	0.17	....
C-Mn-Mo-V	1032	0.23	1.14	0.009	0.035	0.13	0.50	0.09
C-Mn-Mo-V	L5061	0.24	1.17	0.005	0.021	0.18	0.48	0.12



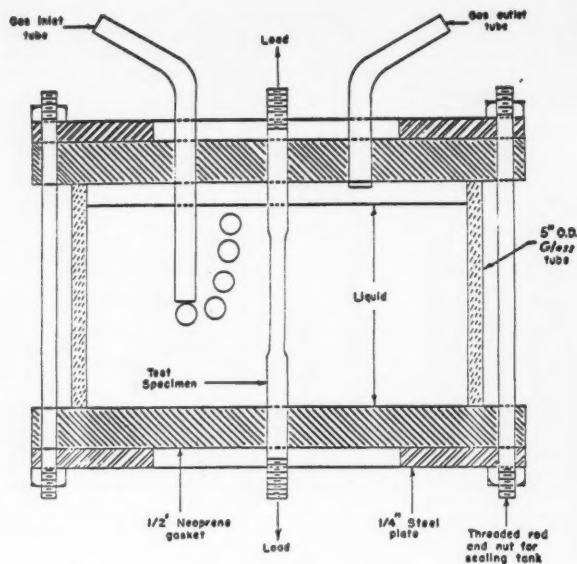


Figure 2—Cross section of tensile corrosion specimen in test jacket.

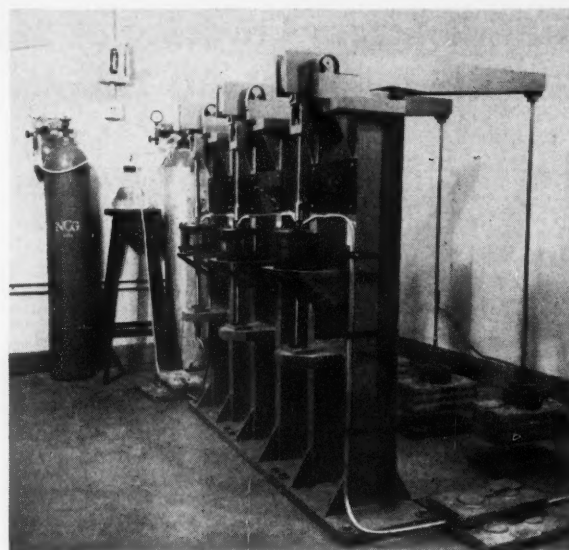


Figure 3—Creep machines for dead weight load testing of sulfide stress cracking specimens.

All sulfide stress cracking tests in this investigation employed the tensile-type specimen shown in Figure 1. The specimens were tested by sealing them in a test jacket containing the corrosive environment, as shown in Figure 2, and loading them in tension in modified high temperature creep machines as shown in Figure 3. This is the test method used by Bloom<sup>3</sup> with the exception that the reduced section is straight and longer. These specimens were machined 0.004-inch oversize in the reduced section, polished circumferentially and then finished longitudinally with 2/0 metallographic paper. The specimens were free of transverse scratches. Test specimens from N-80 tubing were machined from longitudinal strips cut from the wall of the heat-treated tubing. Test specimens of the C-Mn-Mo-V alloy were machined from the 1/2-inch square heat-treated blanks.

Sulfide stress cracking tests were made on samples in the as-heat-treated condition, and also after cold working to determine what effect cold working (which is experienced in rotary straightening) might have on sulfide failures of tubing steels. Specimens were cold worked by stretching in a tensile machine to a level of 1 percent permanent strain. This level was chosen as it represents two to four times the average change in length of a tube during rotary straightening. An extensometer was attached to the sample during this operation and the amount of permanent strain after releasing the load was so determined. Cold worked samples were placed in the sulfide test in the same day in which they were strained.

Prior to testing, each sample was degreased in trichloroethylene, arranged in a test jacket as shown in Figure 2, and then placed in a creep machine. The jacket surrounding the specimen was purged with nitrogen during application of the load. After loading, 600 ml of nitrogen-purged distilled water contain-

TABLE 2—Heat Treatments and Mechanical Properties of Steels Used in Sulfide Stress Cracking Tests

Grade	Heat No.	Heat Treatment*	Yield Strength, Psi	Tensile Strength, Psi	Percent Elong.**	Hardness Rc
N-80	7591	Normalize 1600F	90,550	123,950	15.5	24
N-80	7591	Normalize & Temper 1150F	83,475	108,625	20.0	18
N-80	7591	Normalize 1600F & Temper 1200F	79,000	104,050	21.3	16
N-80	6538	Normalize 1600F	84,000	130,000	20.0	22
N-80	6538	Normalize 1600F & Temper 1150F	82,950	108,200	20.3	17
N-80	6538	Normalize 1600F & Temper 1200F	80,250	104,900	22.5	16
C-Mn-Mo-V	1032	Normalize 1600F & Temper 1300F	87,750	101,800	23.0	17
C-Mn-Mo-V	L5061	Normalize 1600F	93,050	106,300	22.5	18
C-Mn-Mo-V	Ingot A	Normalize 1600F & Temper 1300F	90,525	106,400	23.0	18
C-Mn-Mo-V	L5061	Normalize 1600F & Temper 1300F				
C-Mn-Mo-V	Ingot B	Normalize 1600F & Temper 1300F				

\*—1 hour for each operation.

\*\*—Percent Elongation on N-80 heats was taken over a 2 inch gage length on strip tensile tests. Percent Elongation on C-Mn-Mo-V heats was taken over a 1 inch gage length on 0.250 inch diameter tensile tests.

ing 1/2 percent acetic acid (HAc) was added,<sup>4</sup> the gas inlet and outlet tubes were connected and the test was in progress, as shown in Figure 3. A continuous stream of a 50/50 mixture by volume of H<sub>2</sub>S and CO<sub>2</sub> was bubbled through the jacket which kept the solution saturated with these gases during the test cycle. Timers connected to the creep machines measured the time to failure to 0.1 hour. Each specimen was exposed under load in the corrosive environment until it failed, or with few exceptions, until 1000 hours passed. At the termination of the test cycle, each of the specimens which had lasted 1000 hours or more was cathodically cleaned of its corrosion products in a caustic solution, and the loss in diameter measured to obtain an estimate of the amount of corrosion.

### Results and Discussion

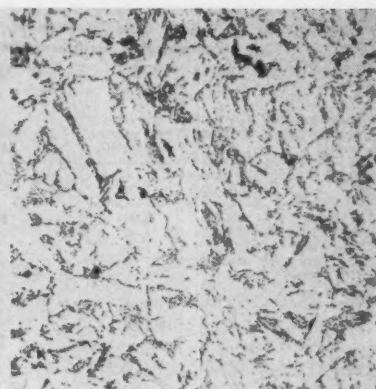
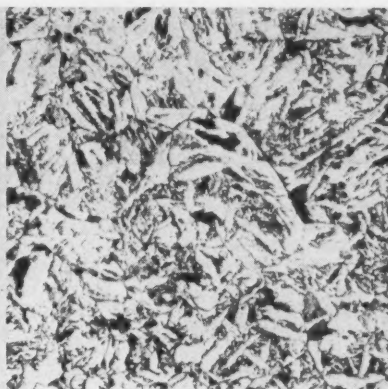
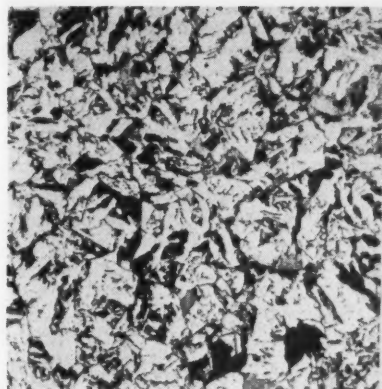
Samples from N-80 tubing from Heat 7591 were tested in the acidified sulfide solution in the normalized condition and also after 1 percent cold working. The

TABLE 3—Results of Sulfide Stress Cracking Tests on Normalized N-80 (Heat 7591) in 1/2 Percent Acetic Acid Sulfide Solution

Applied Stress, Psi	Time to Failure, Hours	Loss in Diameter Due to Corrosion, Inches
100,000	2.1	.....
100,000	2.3	.....
100,000	2.5	.....
90,000	3.9	.....
90,000	4.0	.....
85,000	4.8	.....
85,000	5.7	.....
80,000	6.1	.....
80,000	14.7	.....
80,000	47.9	.....
80,000	181.0	.....
75,000	14.7	.....
75,000	50.4	.....
75,000	N.F.* in 1006.2 Hours	0.0045
75,000	N.F. in 1001.5 Hours	0.0045
70,000	N.F. in 1004.0 Hours	0.0046
70,000	N.F. in 1046.0 Hours	0.0058
60,000	N.F. in 1003.0 Hours	0.0057
60,000	N.F. in 1003.0 Hours	0.0055

\* N.F.—No Failure.





A  
C-Mn-Mo N-80, normalized 1600 F. Electrolytic etch, 1000X.

B  
C-Mn-Mo N-80, normalized 1600 F and tempered 1150 F. Electrolytic etch, 1000X.

C  
C-Mn-Mo-V steel normalized 1600 F and tempered 1300 F. Electrolytic etch, 1000X.

Figure 4—Microstructures of normalized tubular steels. It should be noted that N-80 tempered at 1200 F has the same microstructure as shown.

results are shown in Tables 3 and 4. Specimens of the as-normalized material had a maximum load carrying capacity of between 70,000 psi and 75,000 psi in 1000 hours of test. Prestrain of 1 percent causes the load carrying capacity to be lowered to a level of 45,000 psi to 50,000 psi. It has long been known that cold working steel increases the susceptibility to hydrogen embrittlement, probably by increasing the number of dislocations for the precipitation of molecular hydrogen. It is of interest to observe that such a small degree of cold work has a marked effect on the load carrying capacity. There appears to be no dependence of corrosion rate on applied stress, and no difference in corrosion rate between as-heat-treated and cold-worked material.

Normalized and tempered samples from Heat No. 7591 were also tested in the acidified sulfide solution. The tempering temperature of N-80 tubing to be used in sulfide wells is generally specified at 1100 F min. or 1150 F min. Two tempering temperatures were used in this investigation: 1150 F and 1200 F. Two levels of tempering temperature were employed to determine if resistance to cracking increased with an increase in tempering temperature. All the tempered N-80 specimens were prestrained 1 percent before testing as this was the more severe condition for the normalized N-80. The results of these tests are shown in Table 5. The 1150 F tempered material has a load carrying capacity of between 65,000 psi and 75,000 psi; that of the 1200 F tempered material is between 65,000 psi and 70,000 psi. The corrosion rate, as indicated by the loss in diameter in 1000 hours, in either case is comparable to normalized N-80.

Samples from a second heat of N-80 tubing (Heat No. 6538) were tested after normalizing and tempering at 1150 F and 1200 F. All specimens from this second heat were also tested in the 1 percent cold-worked condition. The results of this second heat are shown in Table 6. The 1150 F tempered material has a load carrying capacity between 70,000 psi and

TABLE 4—Results of Sulfide Stress Cracking Tests on Normalized and 1 Percent Cold Worked N-80 (Ht. 7591) in 1/2 Percent HAc Sulfide Solution

Applied Stress, psi	Percent Permanent Prestrain	Time to Failure, Hours	Loss in Diameter Due to Corrosion, Inches
75,000.....	1.03	7.2	.....
75,000.....	1.01	8.7	.....
60,000.....	1.00	38.7	.....
60,000.....	1.00	80.3	.....
55,000.....	1.01	5.8	.....
55,000.....	1.00	11.0	.....
55,000.....	1.02	26.5	.....
55,000.....	1.03	105.1	.....
50,000.....	1.05	64.3	.....
50,000.....	1.02	68.0	.....
50,000.....	1.01	N.F.* in 1147.7 Hours	0.0047
50,000.....	1.00	N.F. in 1006.7 Hours	0.0044
45,000.....	1.00	N.F. in 1006.6 Hours	0.0053
45,000.....	1.01	N.F. in 1004.0 Hours	0.0062
40,000.....	1.01	N.F. in 1001.5 Hours	0.0034
40,000.....	1.03	N.F. in 1005.0 Hours	0.0045

\* N.F. —No Failure.

80,000 psi. The 1200 F tempered material has a load carrying capacity between 70,000 psi and 75,000 psi. The corrosion rate is again comparable to normalized N-80.

Three things are noticeable from the results of the tests on normalized N-80 and on normalized and tempered N-80. First, the corrosion rate is comparable in all cases indicating that the susceptibility to failure, which is measurably different for each set of pre-treatments, is not dependent on corrosion rate. Schuetz and Robertson found that sulfide stress cracking is essentially nothing more than embrittlement caused by hydrogen, generated in the corrosion process, entering the metal. The present results indicate that metallurgical factors have more of an effect than the corrosion rate in this hydrogen embrittlement. Second, it is evident that normalized and tempered N-80 does not suffer the detrimental effects from cold working that are shown by normalized N-80. It is of interest to note, however, that the N-80 tempered at 1150 F tends to have a greater resistance to failure than that tempered at 1200 F. The beneficial effects of temper-

ing are most probably due to the relief of residual stresses. Tempering, however, also reduces the tensile strength as the tempering temperature is increased. The implication is that there is an optimum tempering temperature (assuming a constant tempering time) for this grade of steel resulting in a compromise between the reduction of tensile strength and residual stress, at which point the resistance to sulfide stress cracking is at a maximum. Third, it can be seen from a comparison of Tables 5 and 6 that, for comparable pre-treatments, the maximum load carrying capacity of Heat No. 6538 is 5,000 psi higher than Heat No. 7591. Since the source and pipe size of these two heats are the same, and the tensile properties are equivalent (for a given tempering temperature), it appears that there can be an appreciable spread from heat to heat in the resistance of tempered C-Mn-Mo N-80 to sulfide stress cracking.

After considerable experimentation with different analyses and heat treatments, it was found that the C-Mn-Mo-V alloy in Table 1, normalized at 1600 F and tempered at 1300 F with the resulting tensile properties shown in Table 2,



**TABLE 5—Results of Sulfide Stress Cracking Tests on Normalized, Tempered and 1 Percent Cold Worked N-80 (Ht. 7591) in ½ Percent HAc Sulfide Solution**

Tempering Temperature, °F	Applied Stress, psi	Percent Permanent Prestrain	Time to Failure, Hours	Loss in Diameter Due to Corrosion, Inches
1150	80,000	1.05	15.0	.....
1150	80,000	1.04	24.3	.....
1150	75,000	1.04	28.1	.....
1150	75,000	1.05	46.3	.....
1150	75,000	1.05	N.F.* in 1007.9 Hours	0.0050
1150	75,000	1.05	N.F.* in 1004.8 Hours	0.0032
1150	70,000	1.09	159.8	.....
1150	70,000	1.05	N.F.* in 1003.5 Hours	0.0038
1150	70,000	1.05	N.F.* in 1103.0 Hours	0.0039
1150	70,000	1.04	N.F.* in 1003.4 Hours	0.0047
1150	65,000	1.04	N.F.* in 1075.0 Hours	0.0050
1150	65,000	1.05	N.F.* in 1013.2 Hours	0.0042
1150	65,000	1.05	N.F.* in 1007.2 Hours	0.0036
1150	65,000	1.05	N.F.* in 1004.6 Hours	0.0040
1200	80,000	1.05	20.5	.....
1200	75,000	1.06	23.1	.....
1200	75,000	1.08	45.6	.....
1200	75,000	1.08	51.5	.....
1200	70,000	1.05	27.8	.....
1200	70,000	1.06	38.0	.....
1200	70,000	1.06	N.F.* in 1006.3 Hours	0.0043
1200	70,000	1.06	N.F.* in 1097.5 Hours	0.0037
1200	65,000	1.06	N.F.* in 1011.3 Hours	0.0042
1200	65,000	1.06	N.F.* in 1037.4 Hours	0.0046
1200	65,000	1.06	N.F.* in 1025.2 Hours	0.0078
1200	65,000	1.06	N.F.* in 1026.4 Hours	0.0043

\* N.F.—No Failure

**TABLE 7—Results of Sulfide Stress Cracking Tests on C-Mn-Mo-V Steel (Ht. 1032) Normalized 1600 F and Tempered 1300 F—Tested in ½ Percent HAc Sulfide Solution**

Applied Stress, psi	Percent Permanent Prestrain	Time to Failure, Hours	Loss in Diameter Due to Corrosion, Inches
<b>Heat Treated—No Prestrain</b>			
90,000	None	11.4	.....
90,000	None	33.8	.....
85,000	None	222.3	.....
80,000	None	774.9	.....
80,000	None	981.0	.....
75,000	None	N.F.* in 1011.6 Hours	0.0042
75,000	None	N.F.* in 1079.4 Hours	0.0039
<b>Heat Treated With 1 Percent Prestrain</b>			
80,000	1.09	727.4	.....
80,000	1.00	N.F.* in 1102.1 Hours	0.0039
75,000	1.02	N.F.* in 1154.4 Hours	0.0050
75,000	1.09	N.F.* in 1004.1 Hours	0.0040
70,000	1.00	N.F.* in 2013.3 Hours	0.0053
60,000	1.05	N.F.* in 2256.0 Hours	0.0054
50,000	1.00	N.F.* in 2515.2 Hours	0.0093

\* N.F.—No Failure.

gave the best combination of mechanical properties, resistance to sulfide stress cracking, and the possibility of being economically feasible for use in N-80 tubing. The results of tests from experimental Heat No. 1032 are shown in Table 7. The load carrying capacity is between 75,000 psi and 80,000 psi in the as-heat-treated condition and also after 1 percent cold work. The corrosion loss is the same as for tests from N-80 tubing.

Specimens from a 100-lb. heat of the C-Mn-Mo-V steel (Heat No. 5061) were tested in the cold worked condition. The results are shown in Table 8. These data indicate the load carrying capacity of this heat in an acidified sulfide solution to be also between 75,000 psi and 80,000 psi. There was only one failure at 75,000 psi and this was after an exposure time

of 700 hours. This sample was from Ingot A. In addition, other samples from Ingot A showed a rather erratic response in corrosion resistance, as compared to samples from Ingot B. The only difference between the two ingots was the degree of hot working. Ingot B was reduced to approximately ¼ the cross section of A. The erratic behavior of samples from Ingot A compared to Ingot B could be due to a lesser degree of homogeneity of structure in Ingot A because of the smaller degree of cast structure refinement.

The microstructures of normalized

**TABLE 6—Results of Sulfide Stress Cracking Tests on Normalized, Tempered and 1 Percent Cold Worked N-80 (Ht. 6538) in ½ Percent HAc Sulfide Solution**

Tempering Temperature, °F	Applied Stress, psi	Percent Permanent Prestrain	Time to Failure, Hours	Loss in Diameter Due to Corrosion, Inches
1150	80,000	1.04	14.2	.....
1150	80,000	1.05	308.1	.....
1150	80,000	1.05	N.F.* in 1101.8 Hours	0.0044
1150	80,000	1.05	N.F.* in 1072.9 Hours	0.0046
1150	75,000	1.04	146.0	.....
1150	75,000	1.04	N.F.* in 1000.8 Hours	0.0060
1150	75,000	1.03	N.F.* in 1005.3 Hours	0.0040
1150	75,000	1.03	N.F.* in 1000.2 Hours	0.0044
1150	70,000	1.04	N.F.* in 1001.1 Hours	0.0053
1150	70,000	1.04	N.F.* in 1000.3 Hours	0.0045
1150	70,000	1.05	N.F.* in 1000.1 Hours	0.0039
1150	70,000	1.05	N.F.* in 1000.0 Hours	0.0050
1200	80,000	1.06	14.5	.....
1200	80,000	1.06	15.9	.....
1200	80,000	1.06	24.7	.....
1200	80,000	1.06	159.1	.....
1200	75,000	1.05	27.9	.....
1200	75,000	1.06	N.F.* in 1001.1 Hours	0.0053
1200	75,000	1.05	N.F.* in 1005.9 Hours	0.0045
1200	75,000	1.06	N.F.* in 1001.3 Hours	0.0032
1200	70,000	1.05	N.F.* in 1027.8 Hours	0.0055
1200	70,000	1.06	N.F.* in 1028.4 Hours	0.0037
1200	70,000	1.06	N.F.* in 1079.9 Hours	0.0043
1200	70,000	1.12	N.F.* in 1073.4 Hours	0.0051

\* N.F.—No Failure.

**TABLE 8—Results of Sulfide Stress Cracking Tests on C-Mn-Mo-V Steel (Ht. L5061) Normalized 1600 F and Tempered 1300 F—Tested in ½ Percent HAc Sulfide Solution**

Applied Stress, psi	Percent Permanent Prestrain	Time to Failure, Hours	Loss in Diameter Due to Corrosion, Inches
<b>Ingot A—Rolled to 1½" Plate</b>			
85,000	1.04	8.2	.....
85,000	1.05	10.6	.....
85,000	1.12	12.2	.....
80,000	1.06	14.8	.....
80,000	1.05	15.1	.....
80,000	1.03	636.4	.....
80,000	1.04	N.F.* in 1005.8 Hours	0.0041
75,000	1.05	700.6	.....
75,000	1.06	N.F.* in 1001.2 Hours	0.0072
75,000	1.05	N.F.* in 1000.2 Hours	0.0084
75,000	1.04	N.F.* in 1004.3 Hours	0.0030
75,000	1.03	N.F.* in 1000.3 Hours	0.0041
<b>Ingot B—Press Forged to 1½" Square Bar</b>			
85,000	1.03	15.5	.....
85,000	1.04	34.3	.....
85,000	1.05	60.8	.....
80,000	1.03	22.1	.....
80,000	1.04	38.7	.....
80,000	1.06	641.0	.....
80,000	1.06	N.F.* in 1004.2 Hours	0.0036
75,000	1.04	N.F.* in 1001.9 Hours	0.0047
75,000	1.05	N.F.* in 1006.9 Hours	0.0045
75,000	1.03	N.F.* in 1029.7 Hours	0.0046
75,000	1.03	N.F.* in 1006.6 Hours	0.0046
75,000	1.05	N.F.* in 1006.6 Hours	0.0053

\* N.F.—No Failure.

N-80 tubing, normalized and tempered N-80 tubing, and the C-Mn-Mo-V alloy are shown in Figures 4a, 4b and 4c. The C-Mn-Mo-V steel, Figure 4c, is lower in carbon and higher in alloy content than the C-Mn-Mo N-80 which accounts for its difference in structure. This difference in structure apparently is favorable to sulfide stress cracking resistance.

Comparing the test results of the C-



Mn-Mo-V steel with those of normalized N-80 shows that this experimental steel has a higher resistance to sulfide cracking and in addition is relatively immune to the harmful effects of 1 percent prestraining exhibited by normalized N-80. The fact that cold work did not seem to increase the susceptibility of the experimental steel to sulfide cracking is an important factor. N-80 tubing is usually rotary straightened, and the facilities of many pipe mills provide only for this type of straightening on a production basis. The possibility of straightening the C-Mn-Mo-V steel without harmful effects is significant. Although tempering N-80 nullifies (partially, if not entirely) the detrimental effects of subsequent 1 percent cold work, the results show a considerable range in resistance to sulfide stress cracking. The C-Mn-Mo-V alloy is equivalent to or slightly better than the best results achieved by the tempered N-80; but, of more importance, the resistance to sulfide stress cracking is more consistent and not subject to variations from heat to heat as N-80 appears to be. The C-Mn-Mo-V alloy has the additional advantage of having a yield strength which could be expected to be consistently above 80,000 psi. Tempered N-80, on the other hand, often falls below 80,000 psi yield and may even go below the 75,000 psi min. yield often specified for sulfide well service.

### Summary and Conclusions

An investigation was conducted in which a comparison was made of the sulfide stress cracking resistance of normalized N-80, normalized and tempered N-80, and a normalized and tempered C-Mn-Mo-V steel with an 80,000 psi minimum yield strength. All corrosion testing was conducted with dead weight loaded specimens in a 1/2 percent acetic acid solution saturated with a 50/50 mixture of H<sub>2</sub>S and CO<sub>2</sub>. Specimens were exposed under load in this environment for 1000 hours unless failure occurred sooner. Tests were made on specimens from the following combinations of steels and pre-treatments: Normalized N-80 tubing; normalized N-80 tubing with the samples prestrained 1 percent before testing; normalized and tempered N-80 tubing with the samples prestrained 1 percent before testing; C-Mn-Mo-V steel as heat treated (normalized and tempered); C-Mn-Mo-V steel as heat treated with the samples prestrained 1 percent before testing.

On the basis of the results of this investigation, the following observations and conclusions can be made.

1. Specimens from normalized C-Mn-Mo N-80 tubing had a maximum load carrying capacity between 70,000 psi and 75,000 psi.
2. Specimens from normalized N-80 tubing, which were cold worked 1 percent prior to testing, had a maximum load carrying capacity between 45,000 psi and 50,000 psi.

3. Specimens from N-80 tubing which was tempered at 1150 F, or 1200 F, and were prestrained 1 percent before exposure, had a maximum load carrying capacity of 65,000 psi to 80,000 psi.

4. When tested in the prestrained condition, specimens from N-80 tubing tempered at 1150 F had approximately 5,000 psi higher load carrying capacity than specimens from N-80 tubing tempered at 1200 F.

5. The corrosion rate of specimens from N-80 tubing, as measured by loss in diameter of a 3/16-inch diameter specimen, was about 0.005-inch in 1000 hours. There is no dependence of corrosion rate on prior thermal or mechanical treatment or on applied load.

6. The experimental C-Mn-Mo-V steel, tempered at 1300 F, had a maximum load carrying capacity of between 75,000 psi and 80,000 psi both in the as-heat-treated condition and after 1 percent prestraining. The corrosion rate was the same as for N-80.

### References

1. A. E. Schuetz, and W. D. Robertson. Hydrogen Absorption, Embrittlement and Fracture of Steel. *Corrosion*, 13, No. 7, 437-458t (1957) July.
2. Symposium on Sulfide Stress Corrosion. *Corrosion*, 8, No. 10, 326-360t (1952) October.
3. F. K. Bloom. Stress Corrosion Cracking of Hardenable Stainless Steels. *Corrosion*, 11, No. 8, 351-361t (1955) August.
4. J. P. Fraser and R. S. Treseder. Resistance of Tubular Materials to Sulphide Corrosion Cracking. *Transactions ASME*, 77, 817-825 (1955).
5. L. W. Vollmer. The Behavior of Steels in Hydrogen Sulfide Environments. *Corrosion*, 14, No. 7, 324-328t (1958) July.

Any discussion of this article not published above  
will appear in June, 1962 issue



# Oxidation Reduction Potential as a Control Criterion In Inhibition of Refinery Sulfide Corrosion\*

By C. B. HUTCHISON\* and W. B. HUGHES\*\*

## Introduction

THE USE OF organic corrosion inhibitors for the protection of refinery distillation equipment has grown rapidly in the past ten years, and has been the subject of many publications.<sup>1,2,3,4</sup> For protection of crude oil distillation equipment, standard practice has been to introduce ammonia into the overhead streams to achieve neutralization of the strong acid content and to maintain the aqueous condensate at a pH of 7 or more. Continuous injection of an inhibitor at low concentration has been capable, under these conditions, of eliminating most of the costly corrosion of refinery equipment. This procedure has been successful in numerous cases; however, some problems have developed as a result of the treatment scheme. Of primary importance among these problems is the control of pH, which many times is not held constant at a control point with the present equipment. If excess ammonia is added, problems of product quality, fouling and corrosion by ammonium salts are expanded to an important magnitude. On the other hand, the addition of too little ammonia will result in corrosion acceleration due to the high hydrogen ion concentration.

Several years ago one refinery discovered that it could overcome many of its subsidiary problems and still maintain adequate corrosion protection through operation at a pH level somewhat lower than usual with the use of only that quantity of ammonia sufficient to neutralize the strong acids present. This refinery's experience has been reported in two papers by Biehl and Schnake.<sup>5,6</sup> Tretolite's search group has followed with interest these refinery developments and has directed efforts in both the laboratory and at refineries toward a study of low pH protection by organic inhibitors. These studies are by no means complete but they have brought forth certain facts which should be of interest to refiners. Based on refinery operation experience, it is apparent that operation at lower pH is not the unqualified answer to the control of corrosion and related problems in a refinery. Some refineries are operating adequately at low pH levels while others are operating adequately at pH 7 or above. This work has been directed toward predicting the optimum operating pH for each refinery.

\*Submitted for publication January 5, 1960. A paper presented at the 17th Annual Conference, National Association of Corrosion Engineers, Buffalo, New York, March 13-17, 1961.

\* Tretolite Company Division, Petrolite Corporation, St. Louis, Mo.

\*\* Formerly with Tretolite Company Division, Petrolite Corporation, St. Louis, Mo. Now at Armour Chemical Division, Dallas, Texas.

## Abstract

The effect of the sulfide on the corrosion of refinery crude unit overhead equipment is considered, using oxidation reduction potential (redox) as a criterion of sulfide content. The study shows that optimum operating conditions are established through careful injection of ammonia to control pH, redox, and sulfide content of the overhead water. Laboratory data are presented to show the influence of changes in pH and redox on corrosivity and on the effectiveness of various corrosion inhibitors. Application of the findings of this investigation to refinery practice is illustrated. 3.6.5, 8.4.3

In crude still equipment, corrosion may be due to a number of agents, including acids present in the charge stock or formed during processing.<sup>7</sup> Various salts such as ammonium chloride and ammonium sulfide formed in the unit from ammonia used for pH control also contribute to corrosion. Several problems are ever present in control of pH, most of which can be traced to inadequate sensitivity of control and metering equipment. Associated with the problem of adequate pH control is the more ponderous problem of the optimum control point. This point is dependent upon the individual situation and must be worked out in each case by a careful evaluation of the particular refinery.

In practice it has been found that a more adequate control of corrosion in a refinery crude unit can be attained by means of oxidation-reduction potential control coupled with pH adjustment than by means of pH control alone. Oxidation-reduction potential is pH-sensitive,<sup>8</sup> but in refinery or buffered waters redox cannot be predicted from a theoretical study. (The term redox where used in this paper is an abbreviation for oxidation reduction potential in millivolts.) In an environment containing excess sulfide, as in many refineries, the electrode potential is governed by the solubility of the sulfide in the aqueous phase of the system. Thus, as the pH increases in the system from ammonia addition, the amount of sulfide ion which distributes to the aqueous phase from the hydrocarbon phase increases. Associated with this increase may be an increase in the corrosion rate up to the point where hydroxyl ions begin to compete with the sulfide ions for the metal surface. The result of higher hydroxyl ion concentration is a lower corrosion rate. At pH values below 4 the concentration of hydrogen ion increases the corrosion rate and appears to be the controlling factor in the corrosion process.

## Experimental Data and Discussion

The corrosivity of synthetic refinery waters was tested in a 21 hour, 140 F,

rotated bottle, two phase, coupon weight loss test. Fifty ml of mineral spirits, and 100 ml of synthetic refinery water were poured into an 8-ounce soda bottle. Sand blasted, weighed coupons, 7/8 inch by 1/8 inch by 1/8 inch, of 1020 carbon steel, were used. The coupons were water wet for five minutes in H<sub>2</sub>S saturated water, pH 4, redox -270, to get a uniform sulfide coating.

Each water wet coupon was put into a bottle containing the fluids. This bottle was purged with hydrogen sulfide, capped and then rotated for 21 hours at 140 F. The coupons were removed, cleaned, desiccated, and reweighed. The oil was removed from the bottles using suction after the coupons were removed, and the final pH and redox were then run on the water to insure that the test condition had been maintained fairly constant.

Refinery waters predominantly contain ammonium chloride, H<sub>2</sub>S, and ammonium sulfide. Synthetic refinery waters containing these products were used in the laboratory tests. Since crude-unit hydrocarbon usually contains ample hydrogen sulfide to saturate the small amount of condensed water in an overhead system, saturated H<sub>2</sub>S waters were used in laboratory testing. Increasing pH and more negative redox values were obtained by adding ammonium sulfide. pH values lower than 4 were obtained by adding hydrochloric acid. The pH and redox of the synthetic refinery waters before and after the test were plotted against the weight loss of the coupon calculated to MPY.

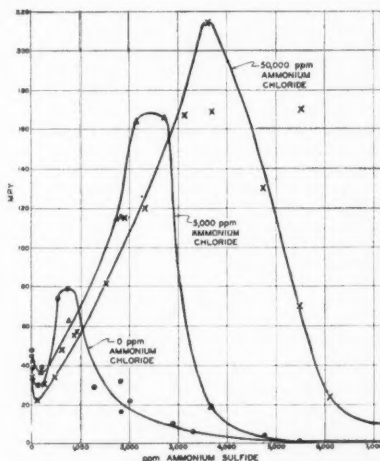


Figure 1—Effect of ammonium sulfide concentration on corrosivity of ammonium chloride hydrogen sulfide saturated brine in two phase agitated 140 F corrosion test (uninhibited).



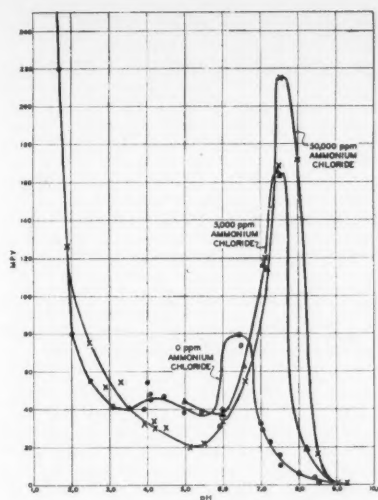


Figure 2—Effect of initial pH on corrosivity of ammonium chloride hydrogen sulfide saturated brine in two phase agitated 140 F corrosion test (uninhibited).

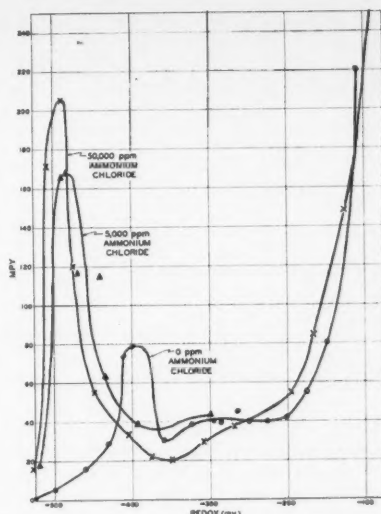


Figure 3—Effect of initial redox on corrosivity of ammonium chloride hydrogen sulfide saturated brine in two phase agitated 140 F corrosion test (uninhibited).

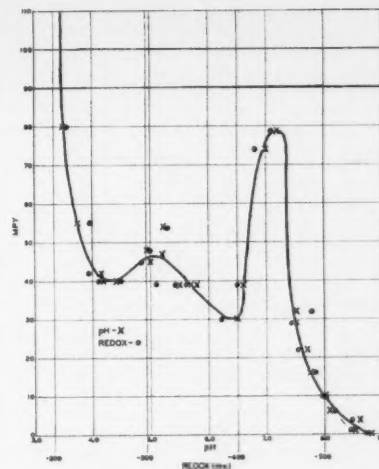


Figure 4—Effect of final pH and redox on corrosivity of hydrogen sulfide saturated water in two phase agitated 140 F corrosion test (uninhibited).

The results of these laboratory investigations are shown in the curves of Figures 1, 2, 3, and 4. Figure 1 shows the relationship between corrosion and ammonium sulfide content at increasing ammonium chloride concentrations in uninhibited synthetic refinery waters. Refinery accumulator waters usually contain only small amounts of chloride if a desalter is in use, but in laboratory testing high chloride content is usually used to accelerate corrosion. Corrosivity is magnified tremendously with a 5 percent (50,000 ppm) ammonium chloride brine.

Figure 2 shows the relationship between corrosion and initial pH in this system. The zero ppm ammonium chloride curve shows an increase in corrosion rate as the initial pH increases with ammonium sulfide from 5 to 6.5, and then a decrease as the pH increases above 6.5. The maximum shifts from 79 mpy at pH 6.5 at zero ammonium chloride to 215 mpy at about 7.5 pH with 5 percent ammonium chloride brine. At intermediate concentrations of ammonium chloride the maximum corrosion rates are at pH values between 6.5 and 7.5.

The same result is apparent when plotting initial redox versus corrosivity in Figure 3 since redox increases with ammonium sulfide concentration in refinery waters. The maximum corrosivity from ammonium sulfide of the synthetic refinery waters shown in Figure 3 is within the range of —375 to —510 redox. The values between —375 and —200 reflect low ammonium sulfide content and low corrosivity. The corrosion rate at redox values more negative than —510 in this test is very low also, but this water is very high in ammonium sulfide content and fouling potential.

Figure 4 shows the effect of pH and redox on corrosivity at the completion of the test and the shift in pH and redox that has taken place during the test in  $H_2S$  saturated distilled water adjusted with hydrochloric acid or ammonium

sulfide. The maximum corrosivity point from ammonium sulfide has shifted from pH 6.5, redox —400, to pH 7, redox —430 mv. This maximum corrosivity point in the 5,000 ppm ammonium chloride brine has changed to pH 7.9, redox —510. The 5 percent (50,000 ppm) ammonium chloride,  $H_2S$  saturated brine maximum corrosivity point has shifted to pH 8, redox —515 mv. In these and all other curves presented in this work, oxidation-reduction measurements were made by use of a platinum-calomel electrode system. Thus these values are referred to the saturated calomel electrode ( $E_{cal}$ ).

Figures 2 and 4 show that below pH 4, corrosion rate increases rapidly since hydrogen ion is controlling. The redox values associated with the pH values below 4 represent a more severe oxidizing condition than above pH 4. It is believed from oxidation-reduction titration data in sulfide solutions that the unpoised region of the ferrous-ferric ion at low iron concentrations is about —250 to —350 mv oxidation-reduction potential ( $E_{cal}$ ). As redox values become more positive than —250, the ferric ion concentration increases, and at zero mv ( $E_{cal}$ ), almost all of the iron is ferric. The accelerating effect of ferric ion in promoting corrosion is well known.<sup>9</sup> Operation of refinery equipment at redox values more negative than —250 mv in order to minimize the ferric ion content of the effluent water is indicated.

Studies by Ewing<sup>10</sup> have shown that at pH values above 9.0 essentially no sulfide film is formed on an iron surface. It must be concluded that at these high pH values the iron surface becomes passive to sulfide attack, due probably to adsorption of hydroxyl ions coupled with a chemical combination of the sulfide in the system. It follows that at very low pH values the hydrogen ion of the solution dissolves the iron sulfide film or prevents it from depositing.

The intermediate areas of pH and

redox are of interest in refinery corrosion control since it is desirable to avoid both extremes in pH. Considering the area between 4.0 and 8.0 pH, corrosion has been found to be largely governed by the amount of sulfide present in the water phase of the system where it is available to enter into the corrosion reaction. The sulfide available in the hydrocarbon phase is of little direct interest in the corrosion process since it is felt that this constitutes a reserve of sulfide available to the aqueous phase, but it contributes little to the direct corrosion of the equipment.

In the presence of sulfide ion in synthetic refinery waters a measurement of redox constitutes a rapid measure of the amount of ammonium sulfide available, since in this case it is sulfide ion solubility which controls this value. Figure 5 shows the influence of the addition of ammonium sulfide upon the electrode potential of two synthetic refinery waters.

The curves of Figure 6 show the relationship between electrode potential and pH in ammonium sulfide solutions and in a typical refinery crude unit accumulator water. It will be observed that the —250 to —350 redox range of lowest corrosivity in Figure 3 is attained between pH values of 4.5 and 6.0 in a typical refinery crude unit water, but this will vary depending upon the nature of the charge stock to be processed and the processing conditions. It is possible to obtain various redox values at any given pH since exceptional redox conditions may exist in refinery waters as shown in Figure 6 as other ions may contribute to redox. Usually it is ammonium sulfide which controls this value. Unusual redox values may signal a severely corrosive condition. The redox values of synthetic refinery waters containing no ammonium sulfide even vary from —250 mv to —290 mv, depending on concentration of ammonium chloride present.



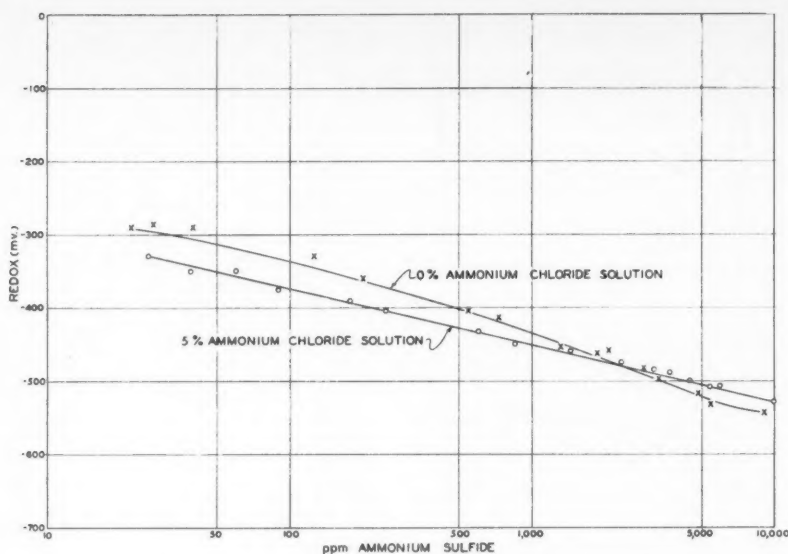


Figure 5—Change in redox with ammonium sulfide concentration in hydrogen sulfide saturated ammonium chloride solutions.

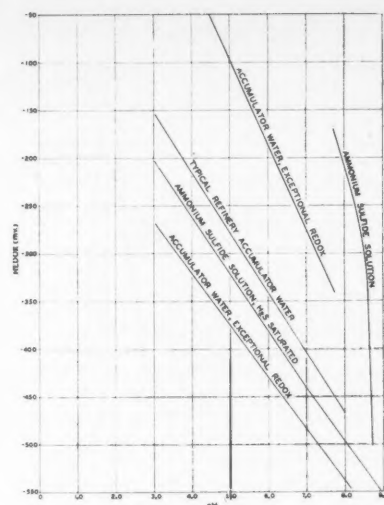


Figure 6—Change in redox with pH in various ammonium sulfide solutions.

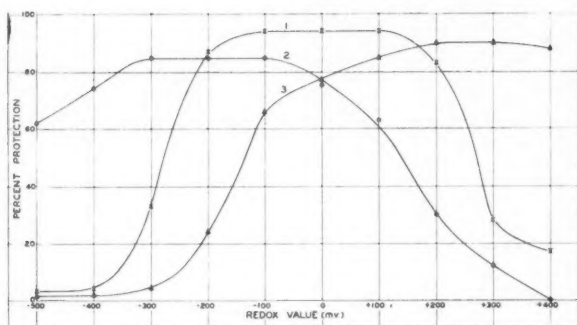


Figure 7—Influence of redox change on efficiency.

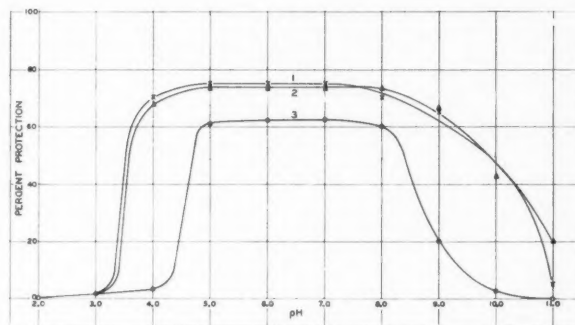


Figure 8—Influence of pH on efficiency.

### Inhibitor Investigations

The factor of redox enters into the practical aspect of the application of inhibitors in corrosion control. Corrosion inhibitors are used in three general conditions and are classified by the conditions in which they are most effective. Those products effective in very low pH, strongly oxidizing conditions with redox varying from highly positive and saturated with oxygen to perhaps a hundred millivolts negative when containing hydrogen sulfide are called "acid inhibitors." "Rust inhibitors" generally function under a moderate oxidizing atmosphere, inhibiting against air, with redox values of the corroding solution as low as zero and up to several hundred millivolts positive ( $E_{cal.}$ ). Inhibitors for hydrogen sulfide or strongly reducing conditions are used from pH 4 to 9 where redox varies from about -200 to values more negative than -500 mv.

Some inhibitor structures are effective in all three conditions, some in only two, and some only one condition. Generally, the most effective inhibitor in one condition is not the most effective in either of the other two general redox ranges.

Some inhibitors have been found to be quite specific in response to both

redox and pH values. The influence of changing redox values at constant pH is illustrated by the curves of Figure 7 in which the percent protection shown by three commercial inhibitors is plotted at various electrode potential values at constant inhibitor concentration and pH. These curves were obtained by use of a dynamic system in which an oil-brine mixture from a refinery was adjusted to pH 6.5 and redox varied using acetic acid, aeration, or de-aeration, hydrogen sulfide, ammonium hydroxide, and reducing agents. This mixture was treated with 150 ppm inhibitor and pumped past a metal plate. The amount of hydrogen evolved by the corrosion process as measured through a thermal conductivity cell was taken as a measure of corrosion.<sup>11</sup> Comparing these values with uninhibited ones allows the calculation of a percent protection figure. The values for percent protection can be somewhat misleading in that no actual accounting for the corrosiveness of the system is made. (A highly corrosive system may exhibit a high apparent protection value and still be quite corrosive.) This response is probably due to variations in the surface ionization characteristics of the metal which are determined in a large measure

by the solution potential (redox). Similarly the inhibitors usually show a definite response to pH conditions.

Figure 8 shows the same inhibitors in their response to changing hydrogen ion concentration of the solution at constant redox. These curves were obtained by measurement of the total iron in solution in a dynamic system<sup>11</sup> in which an oil-brine mixture from a refinery was adjusted to the appropriate pH value and at a redox value of approximately -200 mv. Adjustment was made by using the techniques and agents of the preceding test work along with hydrochloric acid and sodium hydroxide. The mixture was pumped past an iron plate. Protection was first established by the addition of the inhibitor, after which the inhibitor was discontinued. After four hours of contact with the uninhibited fluid readings were made and the curves plotted. This response might be predicted from the dissociation constant of the inhibitors at various pH levels. At the extremely low pH values only inhibitor salts are available for adsorption, while at the extremely high pH values hydroxyl ions compete for the metal surface reducing the inhibitor effectiveness. In practice the pH and redox optimum conditions for



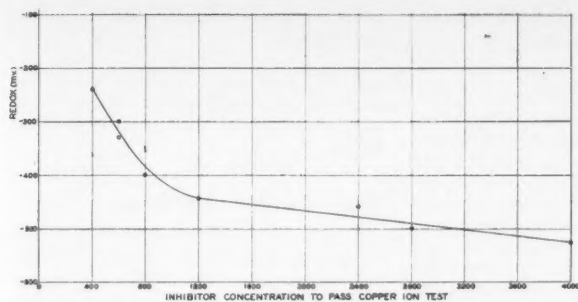


Figure 9—Inhibitor efficiency at various redox values in hydrogen sulfide saturated ammonium sulfide solution in copper ion displacement test.

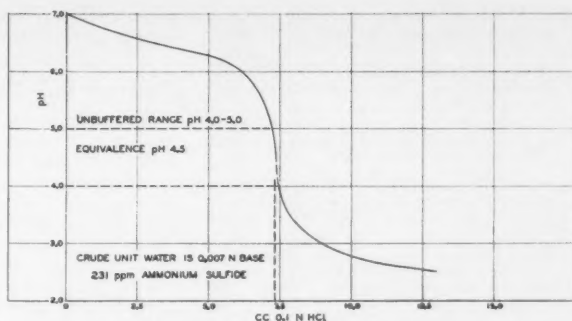


Figure 10—Typical electrometric titration neutralization plot of 100 ml refinery crude unit accumulator water with 0.1 N hydrochloric acid equivalence pH 4.5.

TABLE 1—Effect of pH and Redox on Corrosivity of 5 Percent Ammonium Chloride H<sub>2</sub>S Saturated Brine in Two Phase Agitated 140 F Corrosion Test with 200 ppm Corrosion Inhibitor

Property	Value	
	Case 1	Case 2
Initial pH	4.6	7.5
Initial Redox	-305	-490
ppm (NH <sub>4</sub> ) <sub>2</sub> S	10	3660
Inhibitor Used	Corrosion Rate, mpy	
	Case 1	Case 2
Blank	30	215
Inhibitor A	9	151
Inhibitor B	14	135
Inhibitor C	10	8

an inhibitor shown above and for the unit may not be attainable, so that a compromise must usually be reached.

The effectiveness of inhibitors at changing pH and constant redox; and constant pH-changing redox has been shown. Figure 9 illustrates the change in efficiency of one inhibitor by the copper ion displacement test<sup>12</sup> in synthetic refinery fluids adjusted with ammonium sulfide so that redox changes with pH. Here the -250 redox range requires less inhibitor to pass the test than at more negative redox values.

This same point is illustrated in Table 1 in which two filming amine inhibitors are more effective in the lower redox conditions. A third filming amine inhibitor that is effective in both redox conditions at this inhibitor rate is included also.

#### Practical Application

In practical application it has been found possible to select the optimum pH and redox control points from the pH and redox potential break values of electrometric titrations of the refinery crude unit accumulator water and a pH-redox survey of the unit. Figure 10 shows the electrometric titration plot of the typical overhead accumulator water from an atmospheric crude unit. The plot shows the initial pH of the water, the buffered region from which the equivalent ammonium sulfide content is calculated, the equivalence pH, and the unbuffered pH range. Adjustment of ammonia injection to control slightly above the equivalence pH and redox of the crude unit overhead

water gives operation in an area where the ammonium sulfide is minimized and the strong acid has been neutralized. In this typical plot the equivalence pH is 4.5. The redox value in the plant at pH 4.5 is usually about -250 mv. The redox of the refinery water measured at the equivalence point during the electrometric titration may be slightly more positive than -250 mv because of air stirred into solution. A pH-redox survey of the refinery as the rate of ammonia addition is lowered shows the sulfide content in the refinery water. Selection of an inhibitor which has its optimum activity in the -250 to -350 redox range for a typical refinery makes best use of the capabilities of the chemical when used at the minimum corrosion potential from ammonium sulfide or mineral acid of the system being treated.

The application of this method to refineries can be illustrated by the following case histories.

#### Refinery A

Refinery A had a 24-month tube life in its atmospheric crude tower overhead exchangers, a location where black water contained considerable iron sulfide. This unit experienced many of the fouling problems reported by Ohio Oil Company,<sup>5,6</sup> when operating at pH 7 to 8 with a corrosion inhibitor concentration of 6 ppm. Refinery A lowered its control point to pH 4.6, redox -240, using the same filming amine inhibitor and rate. At this operating condition it eliminated its fouling black water, and corrosion problems. The corrosion on exchanger tubes on turnaround after a 17 month run was nil. The saving in ammonia costs was \$800.00 per month.

#### Refinery B

Refinery B had a corrosion rate of 50-60 mpy by carbon steel resistance probe measurements when running at pH 7.5, redox -480 with 6 ppm corrosion inhibitor. Reducing the pH to 6-7, redox to -440 to -460, cut the corrosion rate in half. Further reduction to a control point of 5.5 pH, -400 redox, gave a 4 to 7 mpy rate. A change to a different filming amine inhibitor at the same use rate further reduced this corrosion rate to the acceptable 2 mpy. pH and redox could not be lowered further since the overhead ammonia injection had

been stopped completely. Savings in ammonia amounted to 3,000 pounds per day.

#### Refinery C

Low pH control was attempted in Refinery C's crude unit, even though the redox data on water there showed that unit should operate at pH 7 or above to obtain redox values more negative than -200 mv. After seven months operation with a corrosion inhibitor at about pH 4.5, redox range -30 to positive, the unit had to be shut down from leaks in overhead exchangers. After repair the unit was operated at pH 6.5 to 7.5 about -250 redox. The corrosion rates by electrical resistance corrosion measuring device probe have been nil since that time.

#### Conclusions and Observations

1. Corrosion in refineries can be reduced by the proper use of organic inhibitors in optimum pH and redox conditions.
2. Optimum conditions for operation can be determined by electrometric titration and a consideration of the equivalence point together with a redox-pH survey in the plant.
3. In practice operating at the optimum is often impractical; however, it is desirable to operate as near this point as possible with the existing equipment.
4. Each refinery must be evaluated individually since the operating conditions and crude charge stocks are not the same in any two refineries.

#### References

1. R. J. Hafsten and K. R. Walston. Use of Neutralizers and Inhibitors to Combat Corrosion in Hydrocarbon Stream. *Proc. API*, 35, (III) 80-91 (1955).
2. H. H. Bennett. Use of High Molecular Weight Corrosion Inhibitors in Refineries. *Corrosion*, 11, 59t (1955) Feb.
3. P. W. Sherwood. Oil Refineries and Corrosion by Water. *Petroleum* (London), 18, 50 (1955).
4. Roy V. Comeaux. Corrosion of Refinery Equipment by Aqueous Hydrogen Sulfide. *Corrosion*, 11, 189t (1955) Apr.
5. J. A. Biehl and E. A. Schnake. Corrosion in Crude-Oil Processing—Low pH vs. High pH. *Proc. API*, 37, (III) 129-34 (1957).
6. J. A. Biehl and E. A. Schnake. Processing Crude Oil at Low pH. *Proc. API*, 39, (III) 214 (1959).
7. G. J. Samuelson. Hydrogen-Chloride Evolution from Crude Oils as a Function of Salt Concentration. *Proc. API*, 34, (III) (1954).



8. L. F. Hewitt. Oxidation-Reduction Potentials in Bacteriology and Biochemistry. E. & S. Livingstone, Ltd., Edinburgh (1950).
9. Herbert H. Uhlig (Editor). The Corrosion Handbook. John Wiley & Sons, Inc., New York, (1948).
10. S. P. Ewing. Electro Chemical Studies of the Hydrogen Sulfide Corrosion Mechanism. *Corrosion*, 11, 497t (1955) Nov.
11. W. R. Scott and Gilson H. Rohrback. A Hydrogen Evolution Method for Evaluation of Corrosion Inhibitors for Oil Wells. *Corrosion*, 8, 234 (1952) July.
12. W. B. Hughes. A Copper Ion Displacement Test for Screening Corrosion Inhibitors. *Journal of Petroleum Technology*, January 1958, (1958).

### DISCUSSION

#### Questions by A. J. Freedman, Nalco Chemical Co., Chicago, Illinois:

1. It is generally accepted that at pH values less than 4, the primary cathodic reaction in the corrosion process is the reduction of hydrogen ions. At pH values above 7, reduction of oxygen or formation of hydroxyl ion is most important. In the pH 4-7 range, both reactions compete. Would you care to speculate as to why corrosion rates should be a minimum in this area?

2. How is formation of a tight, protective scale affected by reactions in this region?

3. How does the sulfide ion concentration affect these reactions?

#### Replies by C. B. Hutchison:

The evidence presented is that corrosion is at a minimum in the -250 mv redox potential area, and that the pH associated with this potential may be 4.5 in one system or 7 in another, but not pH 4-7 disregarding redox. The paper shows that ammonium sulfide is very corrosive to iron below the concentration where hydroxyl ion is controlling, and that redox potential is used as a measure of ammonium sulfide concentration. In the optimum redox range ammonium sulfide is a minimum, and therefore, corrosion rates are also low.

Protective sulfide film formation and the effect of additives in this film deposition have been the subject of an investigation in our research laboratory which has been tentatively scheduled for publication. We prefer to withhold discussion of this subject information until the paper is presented.

#### Questions by Ralph P. Gulley, Gulf Oil Corp., Port Arthur, Texas:

1. Does your information regarding inhibitor performance in relation to redox

potential apply equally well to copper base alloys?

2. Do your case history references apply to overhead systems constructed of copper base alloys, such as admiralty and Monel?

#### Replies by C. B. Hutchison:

1. Yes. The adjustment of pH and redox potentials in overhead accumulator waters of crude units to optimum values eliminates the high concentrations of ammonium and sulfide ions that are corrosive to copper base alloys. High concentrations of salts interfere with the adsorption and filming of some corrosion inhibitors, and the consequent protection obtained by their use.

2. These case history references presented are from refineries with admiralty tubes in the overhead condensers of their crude units. A reduction in copper content of the accumulator waters was reported by the refineries changing from high pH and ammonium sulfide concentration to control conditions that minimized ammonium sulfide.

Any discussion of this article not published above  
will appear in June, 1962 issue

### NACE Guide for Preparation of Articles for Publication

Persons interested in submitting articles on corrosion for publication in CORROSION can obtain upon request a copy of the "NACE Guide for Preparation of Papers." Write to CORROSION, National Association of Corrosion Engineers, 1061 M & M Bldg., Houston 2, Texas.



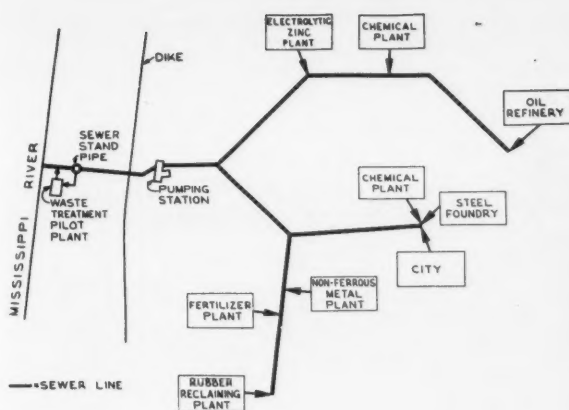


Figure 1—General layout of Monsanto, Illinois, sewerage system.

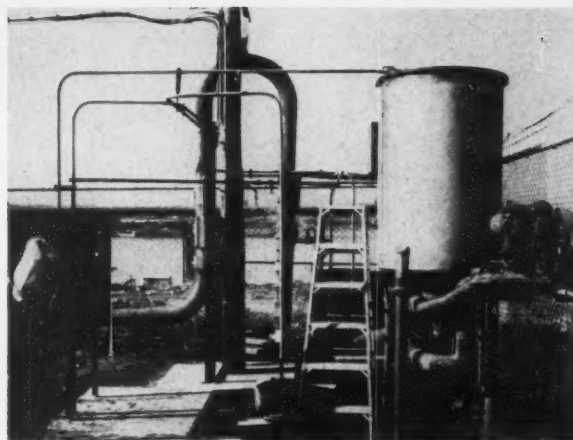


Figure 2—Wastes, directly from sewer, are sampled at pump tank.

## Materials of Construction Tested For Chemical Plant Waste Disposal Facilities\*

By OLIVER W. SIEBERT

### Introduction

THE PROBLEM of disposing of industrial wastes has received much public attention during the past 15 years. Historically, the desire for laws regulating stream pollution has been the province of state and local sportsmen and conservation groups. The Water Pollution Control Act of 1956 allows the federal government to join with state and local agencies.

Monsanto Chemical Company, as most industries, had long accepted its responsibilities and directed efforts in the preventive field of in-plant waste reduction.<sup>1</sup> Since 1959 it has operated a small activated sludge pilot plant and oxidation pond to determine the manner in which company wastes could be treated on a continuous basis and to collect design data.<sup>1,2</sup>

This article will discuss the corrosion investigation conducted in this pilot plant, report test data and present the range of acceptable construction materials for all unit operations of a chemical plant waste disposal facility.

### Environment

The W. G. Krummrich Plant of Monsanto is located south of East St. Louis in Monsanto, Illinois. All its wastes, industrial and sanitary, are discharged to the Mississippi River through the Monsanto village sewerage system. Two main trunk lines which pass through the plant

\* Submitted for publication March 14, 1961. A paper presented at the 17th Annual Conference, National Association of Corrosion Engineers, Buffalo, New York, March 13-17, 1961.

### About the Author



O. W. SIEBERT is Materials Engineering Specialist, Monsanto Chemical Company, Monsanto, Illinois. He has a BS in mechanical engineering from Washington University and did his graduate work in metallurgy at Sever Institute of Technology. On the staff at Washington University he has classes in Engineering Materials and Metallurgy of Iron and Steel. Mr. Siebert is a member of several NACE Technical Committees, Vice Chairman of T-5A, a past chairman of the St. Louis Section and current section Trustee to the North Central Region. He is a member of ASM, ASME, the Research Society of America, and is a registered professional engineer (Missouri).

also carry wastes from six other industries and the sanitary sewage from the village of Monsanto.

The Krummrich Plant produces basic chemicals such as hydrochloric, phosphoric and sulfuric acids, chlorine and caustic, herbicides, insecticides, oil additives and intermediates. Approximately 100 different items are produced using a like number of different raw materials.

### Abstract

Data are reported on the results of tests to determine the range of acceptable construction materials for all unit operations of a chemical plant waste disposal facility. The investigation presented illustrates the corrosion problems encountered in the biological treatment of chemical wastes, stream pollution abatement. The tests were conducted in a pilot plant installed to study the manner in which wastes could be treated on a continuous basis. This activated sludge plant and oxidation pond handled the liquid wastes from a major chemical plant along with those from an oil refinery, zinc plant, casting plant metals reclaiming operation, rubber reclaiming plant, fertilizer plant and domestic sewage. The corrosion study, directed toward criterion requirements for the design and economical maintenance of a full scale, operational secondary waste treatment plant, concludes with recommendations for construction materials. 2.3.8

TABLE 1—Composition of Combined Monsanto Village Sewage Before and After Activated Sludge Treatment

Property	Typical Data of 24-hour Composite Sample Removed From Main Sewer	Typical Data of Effluent Sample Removed After Final Settling Tank
pH.....	3.0	7.9
Settleable Solids.....	2.5 mg/L	0.9 mg/L
Suspended Solids.....	150 ppm	112 ppm
Dissolved Solids.....	2500 ppm	2500 ppm
Chlorides.....	600 ppm	600 ppm
Total Acid.....	300 ppm	.....
COD.....	700 ppm	221 ppm
BOD.....	300 ppm	90 ppm
Phenol.....	50 ppm	4 ppm
Oil.....	25 ppm	4 ppm
Threshold Odor No.....	300	20
Flow.....	36 x 10 <sup>6</sup> gal/day; 2-3 ft/sec.	30 gal/min; 5.2 ft/sec.



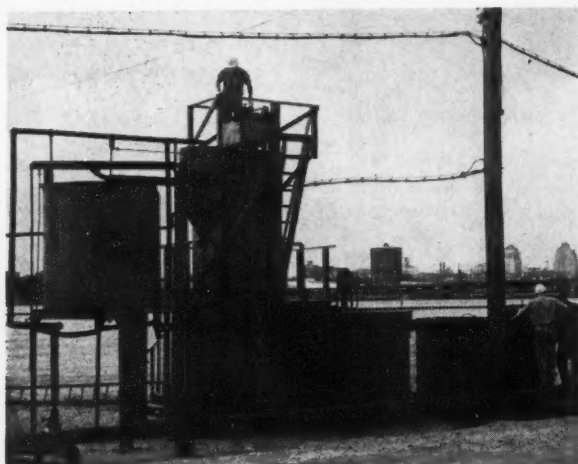


Figure 3—Overall view of waste treatment pilot plant. Wooden tanks on right are neutralizer and hold tanks. Preliminary and final settlers are at left center. Tank at left is aeration tank.

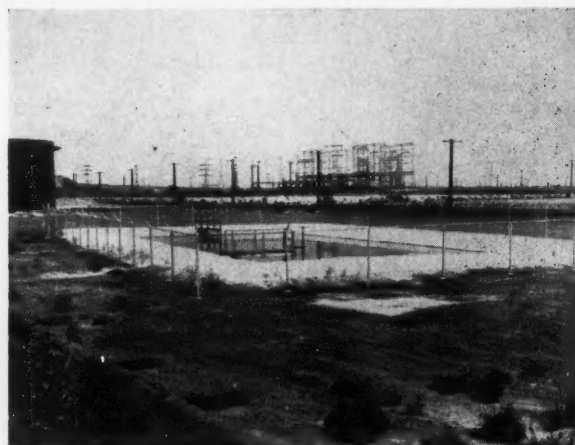


Figure 4—Oxidation pond shown here has an area of 1/10 acre and a depth of 3 feet. Influent is at the left end and overflow at the right.

Wastes from these operations along with wastes from an oil refinery, zinc plant, casting plant, metal reclaiming operation, rubber reclaiming plant, fertilizer plant and domestic sewage make up the composition of the wastes in the village sewers. All sewers join before reaching the Mississippi River and discharge through a single outfall.<sup>1</sup> Figure 1 shows the general layout of the Monsanto village sewerage system.

A typical range of composition of the system waste is shown in table 1.<sup>1,3</sup> Laboratory determinations were made each day on a 24-hour composite sample for the following: pH, settleable solids, suspended solids, dissolved solids, chlorides, total acid, chemical oxygen demand (COD), biological oxygen demand (BOD), phenol, oil and threshold odor number.<sup>1</sup> Figure 2 shows the sampling station.

#### Treatment Theory

Activated sludge plants are a form of aerobic biological treatment of organic waste materials. Liquid waste is aerated by bubbling air through the liquid. Microorganisms form flocculent masses of aerobic bacteria, called activated sludge, that are suspended in the liquid.

In plant operation, sewage is initially presettled. The clarified effluent is contacted with activated sludge microorganisms while being vigorously aerated (which forms more activated sludge). The mixture is gravity separated, with sludge from this clarifier recycled as seed to the biological activity in the aerator. There are at least two reactions that occur. Clarification by adsorption takes about 30 minutes. Oxidation of organic matter in solution and in colloidal/suspended form, after adsorption, takes several hours.<sup>4</sup>

Lagooning is the simplest method of aerobic biological treatment of waste. Organisms usually develop naturally, although seeding of the pond may be accomplished with domestic sewage or

TABLE 2—Results of Corrosion Tests in Main Sewer Pipe and 37 Foot Standpipe After 1819 Hours Exposure<sup>a, b</sup>

Sample Identification	Location of Sample In Standpipe	Average Corrosion Rate	Remarks
Steel.....	Bottom 10' 20' 30'	55 mpy 10 mpy 3 mpy 10 mpy	Concentration cell, cratering Concentration cell, pitting Pitting, rusting Pitting, rusting
Cast Iron.....	Bottom 10' 20' 30'	14 mpy 3 mpy 5 mpy 9 mpy	Graphitization Graphitization Concentration cell, pitting Pitting, rusting
Ductile Cast Iron.....	Bottom 10' 20' 30'	35 mpy 4 mpy 2 mpy 2 mpy	Severe pitting Severe pitting Severe pitting Severe pitting
Ni Resist I.....	Bottom 10' 20' 30'	4 mpy 1 mpy <1 mpy 4 mpy	Pitting, intergranular etch Pitting Pitting Severe pitting
Ni Resist II.....	Bottom 10' 20' 30'	6 mpy 1 mpy <1 mpy 2 mpy	Pitting, intergranular etch Pitting Pitting, intergranular etch Severe pitting, intergranular etch, rusting
Chemical Lead.....	Bottom 10' 20' 30'	<1 mpy <1 mpy 1 mpy <1 mpy	Pitting Pitting Pitting Pitting
80-20 Cu-Ni.....	Bottom 10' 20' 30'	<1 mpy 1 mpy <1 mpy 2 mpy	Pitting Pitting Pitting Pitting
2SH Aluminum.....	Bottom 10' 20' 30'	40 mpy <1 mpy <1 mpy <1 mpy	Severe shallow pitting Light shallow pitting Light shallow pitting Light shallow pitting
201 Stainless Steel.....	Bottom 10' 20' 30'	1 mpy <1 mpy <1 mpy <1 mpy	General light pitting, locally severe General light pitting, locally severe General light pitting, locally severe General light pitting, locally severe
202 Stainless Steel.....	Bottom 10' 20' 30'	3 mpy 1 mpy <1 mpy <1 mpy	Scattered locally severe pitting General light pitting, scattered deep pits General light pitting, scattered deep pits General light pitting, scattered deep pits
304 Stainless Steel.....	Bottom 10' 20' 30'	<1 mpy 1 mpy <1 mpy <1 mpy	Light pitting, intergranular etch Light pitting to cratering Light pitting, scattered deep pits Light pitting, scattered deep pits
316 Stainless Steel.....	Bottom 10' 20' 30'	1 mpy <1 mpy <1 mpy <1 mpy	Incipient pitting Incipient pitting Incipient pitting Incipient pitting
Hastelloy B.....	Bottom 10' 20' 30'	1 mpy 2 mpy 1 mpy 2 mpy	Pitting, intergranular attack, concentration cell attack Pitting, intergranular attack, concentration cell attack Pitting, intergranular attack, concentration cell attack Pitting, intergranular attack, concentration cell attack



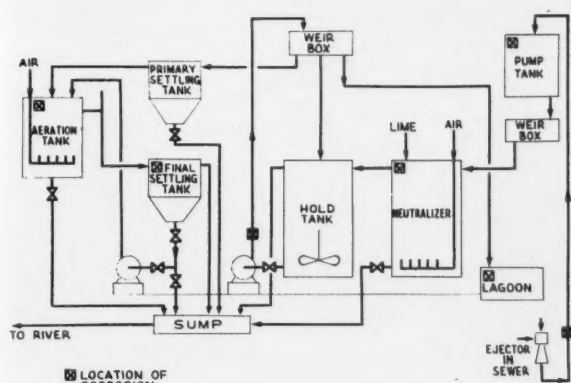


Figure 5—Flow diagram of waste treatment pilot plant.

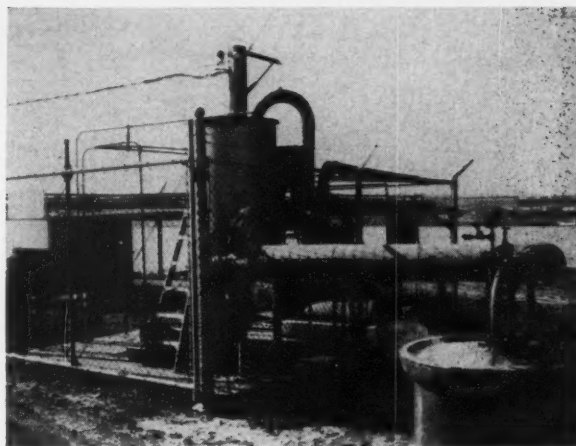


Figure 6—Raw waste, lifted from the sewer by a hydraulic ejector in the standpipe (right foreground), is discharged into the pump tank (upper center).

TABLE 2 (CONTINUED)—Results of Corrosion Tests in Main Sewer Pipe and 37 Feet Standpipe After 1819 Hours Exposure<sup>a, b</sup>

Sample Identification	Location of Sample In Standpipe	Average Corrosion Rate	Remarks
Nickel.....	Bottom 10' 20' 30'	<1 mpy 2 mpy 1 mpy 2 mpy	Light pitting, scattered deep pits Light pitting, scattered deep pits Light pitting, scattered deep pits Light pitting, scattered deep pits
Monel.....	Bottom 10' 20' 30'	<1 mpy 1 mpy 1 mpy <1 mpy	Light pitting, concentration cell Severe cratering Light pitting, concentration cell Severe pitting, intergranular attack
Polyvinyl Chloride, Type II....	Bottom 10' 20' 30'	+ 0.3 P. C. W. <sup>(c)</sup> + 0.004 " + 0.07 " + 0.027 "	Softened, warped, absorbed odors Warped, absorbed odors Warped, absorbed odors Warped, absorbed odors
Polyvinylidene Chloride.....	Bottom 10' 20' 30'	+ 0.26 " + 0.08 " + 0.03 " + 0.01 "	Softened, warped, absorbed odors Softened, warped, absorbed odors Softened, warped, absorbed odors Softened, warped, absorbed odors
Acrylonitrile Butadiene Copolymer	Bottom 10' 30'	— 0.41 " + 0.3 " — 0.2 "	Softened, warped, absorbed odors Softened, absorbed odors Absorbed odors, no degradation
Neoprene.....	Bottom 10' 20' 30'	+30 " +14.6 " + 2.7 " — 0.01 "	Jellied mass material Softened, swelled, sticky, absorbed Distorted, absorbed odors Slight swelling, absorbed odors
Chlorosulfonated polyethylene ..	Bottom 10' 20' 30'	+35 " +13.4 " + 3.5 " + 0.003 "	Softened, swelled, absorbed material Softened, swelled, absorbed material Softened, absorbed odors Absorbed odors
Red Rubber.....	Bottom 10' 20' 30'	+41 " +13 " + 5 " + 0.2 "	Softened, swelled, absorbed material Softened, swelled, absorbed material Softened, swelled, absorbed material Absorbed odors
Polyethylene.....	Bottom 10' 20' 30'	+ 7.2 " + 7.4 " + 4.3 " + 0.01 "	Sticky, darkened, absorbed odors Darkened, absorbed odors Darkened, absorbed odors Darkened, absorbed odors
Polytetrafluoro Ethylene.....	Bottom	.....	Absorbed odors
Pine (Phenolic Treated).....	Bottom 10' 20' 30'	+ 0.5 " + 1.8 " + 1.8 " — 1.4 "	Absorbed material, leaching of soft wood Absorbed material, leaching of soft wood Absorbed material, leaching of soft wood Absorbed odors, bleached
Pine (Furan Treated).....	Bottom 10' 20' 30'	— 0.6 " + 1.1 " + 1.2 " — 1.2 "	Absorbed material, leaching of soft wood Absorbed material, leaching of soft wood Absorbed odors, surface cracking Absorbed odors, bleached

(a) Liquid level in standpipe (river stage) during test averaged 14 foot-20 foot above 4 foot diameter sewer pipe.

(b) Surface of liquid in standpipe covered by an oil layer.

(c) Percent change by weight.

treatment plant effluents. Oxygen is absorbed at the surface from the atmosphere and also results photosynthetically from plankton or algae.<sup>4</sup> Considerable land area is needed because ponds must be shallow and require retention up to 90 days to react. During this time some solids settle, some liquid may be absorbed into the ground and additional purification could come from spontaneous chemical reactions in the wastes.

Aerobic biological treatment is sensitive to poisoning by germicides and heavy metals. Both toxic materials are present in the Monsanto village sewage but experience has shown that the wastes can be treated successfully. Further information is available in other reports.<sup>5, 6, 7, 8</sup>

The activated sludge pilot plant used by the author's company is shown in Figure 3. The associated oxidation lagoon is pictured in Figure 4. Figure 5 shows the flow sheet of the complete system. The waste was pumped from the sewer at a point near the river, to a pump tank shown in Figure 6 (a pump off this tank supplied the power to an ejector located in the bottom of a 37 foot deep sewer standpipe). The waste drained through a stainless steel weir box which controlled the overflow to a 2000 gallon wooden neutralizer tank. The waste was neutralized with lime, pre-aerated, overflowed to a 2000 gallon agitated wooden hold tank and the wastes were blended, (see Figure 7). This material was pumped to a second stainless steel weir box, which controlled the overflow to both a primary settling tank of steel, 3 ft. diameter, and to the lagoon, one tenth acre in size and three feet deep, shown in Figure 4. From the primary settling tank the effluent flowed by gravity to an aeration tank of steel, 6 feet x 6 feet, shown in Figure 8. Later the material overflowed to a final settler, again a 3 ft. diameter steel tank where the biological solids were removed and pumped back to the aeration tank for seed. The purifier effluent



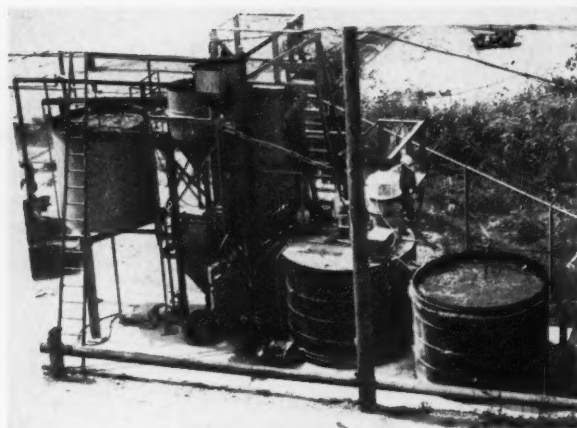


Figure 7—Neutralizer/pre-aeration tank (far right). Hold tank is second from right.

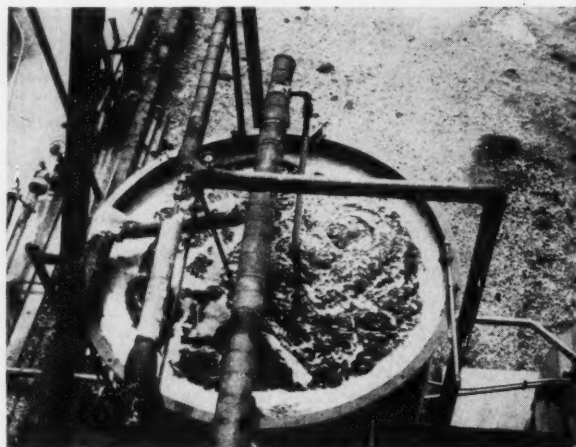


Figure 8—Top view of aeration tank.

overflowed from the settling tank to the river.

One full scale secondary waste treatment plant has been built from data secured from pilot plant studies. This unit, at the Monsanto plant at Anniston, Alabama, is responding to the performance anticipated from the pilot plant studies.<sup>1, 9</sup>

#### Experimental Procedure

Metallic corrosion specimens were prepared from commercial sheet stock, saw cut oversize and then machined to a nominal size of 1/4 inch x 1 inch x 2 inches with a 3/8-inch diameter support hole drilled near one end. Sensitized specimens were made by welding two sheets together, the weld being the longer axis of the completed coupon. All samples were polished to a 120 grit finish and hand stamped for identification.

The size of non-metallic corrosion specimens were 2-3 times the 5.5 square inch area of the metal coupons. They were exposed in an "as-received" condition.

All specimens, except concrete, were electrically insulated and separated from each other and from their support holders by the use of machined fluorocarbon sleeves, washers and spacers. Concrete samples were set in the bottom of the exposure.

Coupon exposures were made in the

TABLE 3—Results of Corrosion Tests in and Above Main Effluent Sluice, Pumping Station, 3096 Hours Exposure<sup>(a)</sup>

Sample Identification	Location of Sample	Average Corrosion Rate, mpy	Remarks
Gray Cast Iron.....	Liquid Vapor <sup>(b)</sup>	26.4 23.8	Pitting Pitting
Ni Resist I.....	Liquid Vapor	1.9 5.3	
Ni Resist D II.....	Liquid Vapor	3.2 8.9	Pitting
90/10 Cu-Ni.....	Liquid Vapor	<0.1 0.1	Profuse incipient pitting Profuse incipient pitting
Bronze, Commercial.....	Liquid Vapor	0.5 1.6	Slight concentration cell attack Pitting
Bronze, 10% Al-5% Ni.....	Liquid Vapor	5.5 1.9	Incipient pitting
Bronze, Ni Vee Type A.....	Liquid Vapor	0.6 2.2	Slight concentration cell attack
Bronze, Ni Vee Type B.....	Liquid Vapor	0.7 2.5	Slight concentration cell attack Pitting
Monel.....	Liquid Vapor	0.3 2.2	Incipient pitting Pitting
Ni-O-nel.....	Liquid Vapor	<0.1 <0.1	
304 Stainless Steel.....	Liquid Vapor	<0.1 0.1	Pitting; crevice attack Pitting; incipient crevice attack
316 Stainless Steel.....	Liquid Vapor	<0.1 <0.1	
Durimet 20.....	Liquid Vapor	<0.1 <0.1	

<sup>(a)</sup> Joint test with International Nickel Co. for U.S. Engineers, St. Louis District; Evaluations by A. J. Marron, Inc.

<sup>(b)</sup> Vapor exposure, in atmosphere, 2 feet above liquid effluent.

TABLE 4—Results of Corrosion Tests in Liquid and at Interface<sup>(a)</sup> of Pilot Plant Pump Tank (1416 Hours Exposure)

Sample Identification	Location of Sample	Average Corrosion Rate	Remarks (Examination at 1X, 5X, 40X)
Steel.....	Liquid Interface	24 mpy 39 mpy	Severe pitting and conc. cell attack Severe pitting and conc. cell attack
304 W Stainless Steel <sup>(b)</sup> .....	Liquid Interface	<1 mpy <1 mpy	Severe conc. cell attack Severe conc. cell attack
316 W Stainless Steel.....	Liquid Interface	.....	No attack No attack
Carpenter 20 W.....	Liquid Interface	.....	No attack No attack
Bronze, ASTM B 144 Lead/Tin.....	Liquid	1 mpy	Uniform shallow pitting
Polyester, modified carbon filled, glass fiber reinforced.....	Liquid Interface	+0.02 Weight Percent Change +0.09 Weight Percent Change	No attack No attack
Concrete, air entrained, 3000 psi (min).....	Liquid	.....	Severe attack on cement

<sup>(a)</sup> Samples exposed at liquid/vapor interface.

<sup>(b)</sup> W designates welded sample.



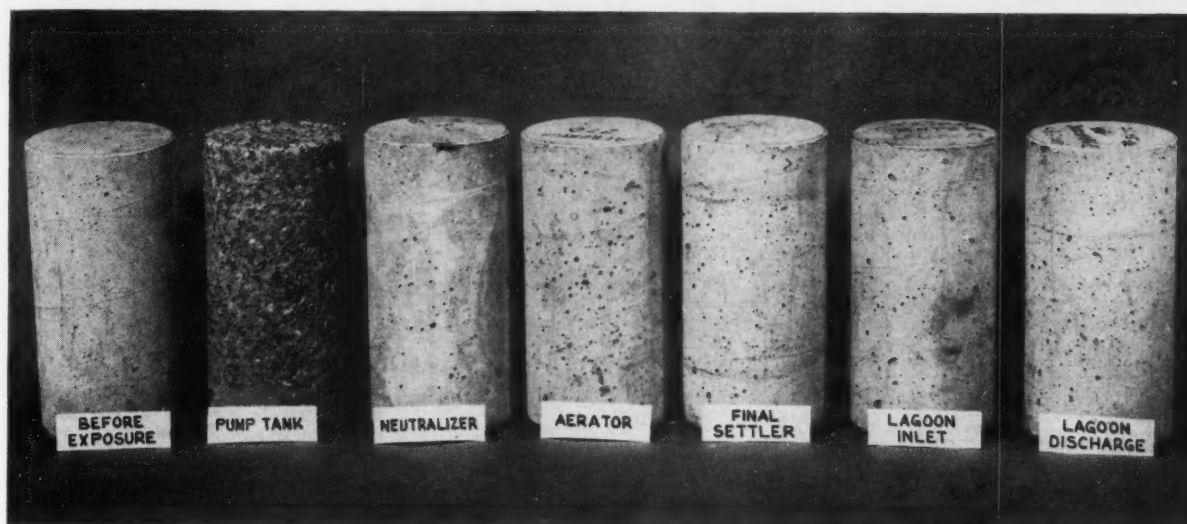


Figure 9—Concrete before and after exposure in pump tank, neutralizer, aeration, final settler and lagoon.

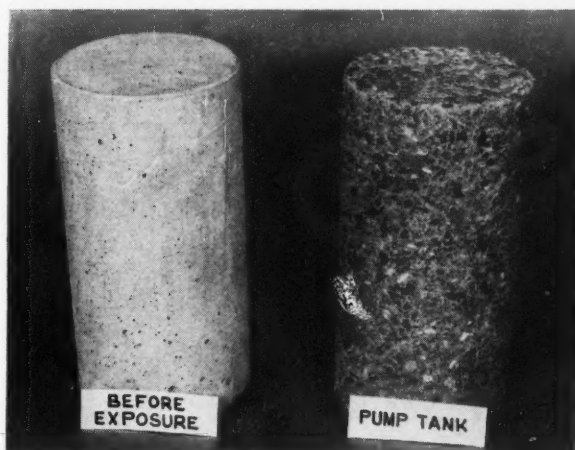


Figure 10—Concrete before and after exposure in pump tank. Note damage.

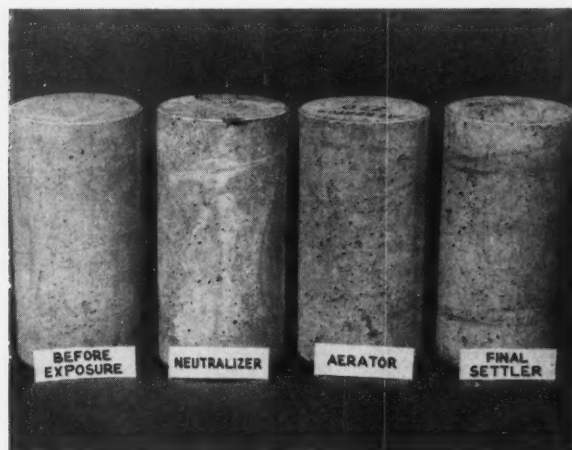


Figure 11—Concrete before and after exposure in neutralizer, aerator and final settler.

**TABLE 5—Results of Corrosion Tests in Liquid and at Interface<sup>(a)</sup> of Pilot Plant Neutralizer,<sup>(b)</sup> 1488 Hours Exposure**

Sample	Location	Rate	Remarks
Steel.....	Liquid Interface	56 mpy 1 mpy	Severe pitting and concentration cell Light pitting, locally moderate
304 W Stainless Steel <sup>(c)</sup> .....	Liquid Interface	<1 mpy <1 mpy	No attack No attack
316 W Stainless Steel.....	Liquid Interface	<1 mpy <1 mpy	No attack No attack
Bronze, ASTM B 144 Lead/Tin.....	Liquid Interface	<1 mpy <1 mpy	General shallow pits General tiny pits
Yellow Pine (Phenolic treated).....	Liquid Interface	+ 9.45 Weight Percent Change +10.98 Weight Percent Change	Absorbed material, leaching of soft wood Absorbed, some splitting
Yellow Pine (Furan treated).....	Liquid Interface	+16.55 Weight Percent Change +19.24 Weight Percent Change	Absorbed material Absorbed material
Redwood.....	Liquid Interface	+ 6.38 Weight Percent Change + 5.15 Weight Percent Change	Bleached, absorbed material Bleached, absorbed material
Concrete, air entrained, 3000 psi (min).....	Liquid		No attack

(a) Samples exposed at liquid/vapor interface.

(b) Agitated with 2 turbine impellers at 90 RPM, 2 diagonally vertical baffles in tank.

(c) W designates welded sample.



pilot plant at eight test stations, locations shown on Figure 5. Samples were tested in the pilot plant and lagoon from 1409 to 3096 hours; two coupons were exposed in the lagoon for only 406 hours.

After exposure, the metallic samples were cleaned of wastes, and products of corrosion, washed with detergent and acetone, dried and weighed. Corrosion rates were calculated from weight loss.

All coupons were examined with the naked eye for obvious defects and studied under the microscope at 5X and 40X. Plastic and wood samples were washed with warm water, dried with absorbent paper/cloth and weighed before they could dry out. These samples were again examined after they were dried to a constant weight. Concrete samples were washed and examined.

### Results and Discussion

Results of all corrosion tests are tabulated in Tables 2 through 9. Corrosion rates and types of corrosion are reported. These latter observations can be controlled over the corrosion rates, *per se*. At the same time, it is no more reasonable to say that only those materials showing uniform attack can be considered for engineering application than it is to accept only those with low corrosion rates. Consider the following example. Type 304 stainless steel suffered less than a mil penetration per year in every exposure series, yet in only the neutralizer tank, Table 5, was the material without pitting or concentration cell damage. Though a material may be known to have excellent resistance, as Type 316 stainless steel, a material having a higher corrosion rate may be more economically suitable for tank construction.

The before and after condition of concrete tested in the pump tank, neutralizer, aeration, final settler and lagoon are shown in Figures 9, 10 and 11.

**TABLE 6—Results of Corrosion Tests in Discharge Pipe Line from Hold Tank Discharge Pump, 1409 Hours Exposure<sup>(a)</sup>**

Sample Identification	Average Corrosion Rate, mpy	Remarks (Examination at 1X, 5X, 40X)
Steel.....	21	Severe pitting, moderate concentration cell
304 W Stainless Steel <sup>(b)</sup> .....	<1	Slight concentration cell
316 W Stainless Steel.....	<1	No attack
Carpenter 20.....	...	No attack
Bronze, Lead/Tin ASTM B 144.....	2	Gross shallow pitting, moderate concentration cell

<sup>(a)</sup> Pump discharged at 30 gpm, 5.2 fps pipe line flow over samples.

<sup>(b)</sup> W designates welded samples.

**TABLE 7—Results of Corrosion Tests in Liquid and at Interface<sup>(a)</sup> of Pilot Plant Aeration Tank, 1488 Hours Exposure**

Sample Identification	Location of Sample	Average Corrosion Rate	Remarks (Examination at 1X, 5X, 40X)
Steel.....	Liquid Interface	62 mpy 4 mpy	Uniform loss plus pitting Severe pitting and concentration cell
304 W Stainless Steel <sup>(b)</sup> .....	Liquid Interface	<1 mpy <1 mpy	Destructive concentration cell No attack
316 W Stainless Steel.....	Liquid Interface	<1 mpy <1 mpy	No attack No attack
Bronze ASTM B 144 Lead/Tin.....	Liquid Interface	1 mpy 1 mpy	Shallow pitting Shallow pitting
Yellow Pine (Phenolic treated).....	Liquid Interface	10.8 Weight Percent Change 8.9 Weight Percent Change	Absorbed material, some splitting Absorbed material
Yellow Pine (Furan treated).....	Liquid Interface	17.31 Weight Percent Change 13.05 Weight Percent Change	Absorbed material, some splitting Absorbed material
Redwood.....	Liquid Interface	5.08 Weight Percent Change 5.16 Weight Percent Change	Grey, absorbed material, split Grey, absorbed material, split
Concrete, air entrained, 3000 psi (min).....	Liquid	.....	No attack

<sup>(a)</sup> Sample exposed at liquid/vapor interface.

<sup>(b)</sup> W designates welded sample.

**TABLE 8—Results of Corrosion Tests in Liquid and at Interface<sup>(a)</sup> of Pilot Plant Final Settler Tank, 1563 Hours Exposure**

Sample Identification	Location of Sample	Average Corrosion Rate	Remarks (Examination at 1X, 5X, 40X)
Steel.....	Liquid Interface	4 mpy 3 mpy	Pitting, severe concentration cell Deep pits, concentration cell
304 W Stainless Steel <sup>(b)</sup> .....	Liquid Interface	<1 mpy <1 mpy	Severe concentration cell Severe concentration cell
316 W Stainless Steel.....	Liquid Interface	<1 mpy <1 mpy	No attack Several isolated deep pits
Bronze, ASTM B 144 Lead/Tin.....	Liquid Interface	<1 mpy <1 mpy	General General
Yellow Pine (Phenolic treated).....	Liquid Interface	8.87 Percent Weight Change 10.04 Percent Weight Change	Bleached, absorbed material, leached soft wood Bleached, absorbed material, leached soft wood
Yellow Pine (Furan treated).....	Liquid Interface	18.97 Percent Weight Change 10.61 Percent Weight Change	Same as phenolic treated + splitting Same as phenolic treated + splitting
Redwood.....	Liquid Interface	5.29 Percent Weight Change 9.05 Percent Weight Change	Same as phenolic treated pine Same as phenolic treated pine
Concrete, air entrained, 3000 psi (min).....	Liquid	.....	No attack

<sup>(a)</sup> Sample exposed at liquid/vapor interface.

<sup>(b)</sup> W designates welded specimen.



### Conclusion

An activated sludge waste treatment plant can be built of economical,<sup>10</sup> commercially available construction materials. Table 10 lists acceptable materials for equipment, pipe and fittings for each unit operation of the biological treatment facility. While some specific selections will vary from one industrial waste treatment installation to another, the environment reported in this test is composite enough to allow most of the results to be accepted as a guide for design.

### Acknowledgment

The author thanks E. G. Wood, Materials Engineer, and B. L. Buatte, Engineering Aide, Monsanto, for their assistance in the conduct of tests. Appreciation is also extended to P. B. Hodges, Waste Control Engineering Specialist and C. N. Stutz, Sanitary Engineer, for their counsel on waste treatment plant design and operation.

### References

1. C. N. Stutz. Monsanto's Pollution Abatement Program in the St. Louis Area. Presented March 15, 1960, at A.I.Ch.E. Spring Symposium, St. Louis Missouri.
2. C. N. Stutz. Pollution Control Measures of Monsanto Chemical Company. Presented November 15, 1960, at Air and Water Pollution Conference, Columbia, Missouri.
3. Metcalf and Eddy, Engineers. Report Upon Waste Treatment for the Village of Monsanto, Illinois, November 3, 1960.
4. C. F. Gurnham. Principles of Industrial Waste Treatment. John Wiley & Sons, Inc., New York, 1955.

TABLE 9—Results of Corrosion Tests in the Inlet to and Discharge from the Pilot Plant Lagoon, Liquid Exposure

Sample Identification	Sample Location	Exposure Time (Hrs.)	Percent Weight Change	Remarks (Examination at 1X, 5X)
Polyester, modified carbon filled, glass fiber reinforced	Inlet	406	+0.04	No attack
	Outlet	406	+0.13	No attack
Concrete, air entrained, 3000 psi (min)	Inlet	1261	.....	No attack
	Outlet	1261	.....	No attack

TABLE 10—Recommended Materials of Construction for All Unit Operations of an Activated Sludge Waste Treatment Plant\*

Unit Operation	EQUIPMENT**				
	Piping	Valves	Pumps	Tanks	Basin
Raw sewage.....	A, B, F, G, I	A, B, C, D, E, I, L	A, B, C, D, E, L	A, B, F, G, I	F
Neutralizer Hold tank Primary Settler....	A, B, G, H, J, K	A, B, C, J	A, B, C, J	A, G, H, K	H
Aeration tank Final Settler.....	A, G, H, K	A, C	A, C	A, G, H, K	H
Lagoon.....					F, H

\* These data summarize the results shown in Tables 2 through 9.

\*\* Types of Material:

- |                              |                         |
|------------------------------|-------------------------|
| A — 316 Stainless Steel      | G — Pine, treated       |
| B — Alloy 20 Stainless Steel | H — Concrete            |
| C — B 144 Bronze             | I — Fluorocarbon        |
| D — Ni Vee Bronze            | J — 304 Stainless Steel |
| E — Ni Resist I              | K — Redwood             |
| F — Polyester, modified      | L — Ni-O-nel            |

5. S. A. Stankey. Effects of Chromium Wastes on Activated Sludge. *Sewage and Industrial Wastes*, 31, No. 4, 496-498 (1959) April.

6. J. F. Mason, Jr., and C. M. Schillmoller. Corrosion in Sour Water Strippers. *Corrosion*, 15, No. 7, 358-362 (1959) July.

7. E. Spindel. Methods of Preventing Corrosion in Sewerage systems. *Corrosion*, 12, No. 3, 136-140 (1956) March.

8. H. J. Keeling. Corrosion Protection Features of the Hyperion Ocean Outfall. *Corrosion*, 15, No. 7, 363-368 (1959) July.

9. Industry & Economic News. Activated-Sludge Process Solves Waste Problem. *Chemical Engineering*, 68, No. 2, 79-80 (1961) January.

10. A. W. Sawyer. Economical Practices in Sewage Treatment Plant Construction. *Sewage and Industrial Wastes*, 31, No. 4, 406-412 (1959) April.

Any discussion of this article not published above will appear in June, 1962 issue



# Use of Aluminum for Portable Sea Water Distillation Equipment\*

By RICHARD J. GAINNEY

## Introduction

SELF-CONTAINED portable sea water distillation equipment for military field use became a major requirement during World War II. Today all of the armed services recognize a potential need for such equipment.

Current standard military distillation equipment is fabricated chiefly from 70-30 or 90-10 cupro-nickel. An alternate material of construction is required because it is anticipated that in the event of mobilization of the military forces, the requirement for nickel for missile or aircraft use would be so great that nickel would not be available for distillation equipment. Also, in the newer concepts of military tactics, the emphasis is on small groups with lightweight equipment.

## Background

The selection of aluminum for investigation for this purpose was also influenced by the work of W. F. Langelier and others at the University of California.<sup>1</sup> While under contract with the U. S. Army Engineer Research and Development Laboratories, they did research on the causes of and prevention of scale in sea water distillation equipment. In the course of their studies they fitted a cupro-nickel unit with an Alclad aluminum evaporator in the hope of eliminating trace amounts of copper in the distilled water from cupro-nickel units. After 3,090 hours of operation they observed that the corrosion was uniformly distributed over the entire surface and that the penetration rate was 0.011 inch per year of continuous service. It was concluded that by assuming a specified tube-wall thickness of 0.109 inch, an Alclad 3S evaporator could be operated for several years under normal conditions without tube failure, and that such an evaporator should outlast several gasoline engines employed in driving the compressor.

## Experimental Unit

To obtain additional information and experience in using aluminum alloys, USAERDL had an experimental vapor compression unit fabricated; this unit was tested on sea water at Kindley Air Force Base, Bermuda. The heat exchangers, evaporator-condenser, and interconnecting piping were fabricated of Alclad 3003 and Alclad 3004. The feed water strainer, pumps, steam compressor, and some control valves were fabricated of bronze or other copper alloys.<sup>2</sup>

The performance of this first aluminum unit on sea water was entirely unsatisfactory. Although the heat exchangers failed completely within 200 hours because of extensive pitting, the

evaporator was unaffected by corrosion thus confirming the results obtained by Langlier. The heat exchangers were of the concentric tube type and contained many "dead spots" which permitted settling out of suspended solids. The corrosion products of aluminum are bulky and tend to accumulate in any quiescent area. Scale and corrosion products, loosened and circulated during the acid cleaning process, were lodged in the annular spaces of the heat exchangers. Copper was found on many parts of the equipment after disassembly of the unit.

The source of copper contamination was determined by analysis of water at various stages. Results are shown in Table 1. These results show that the copper content increases markedly after sea water has passed through the bronze feed water pumps. Aluminum is anodic to most metals in aqueous solutions and it is well known that very severe galvanic action is likely to occur in the presence of copper-base alloys. The amount of copper normally present in sea water is between 0.001 and 0.01 mg/l which is below the level of detection by the analytical procedure used.

The first aluminum distillation was not considered a full success because of pitting in the heat exchangers due to the use of copper equipment. The amount of copper in sea water was considered negligible, and even 0.60 mg/l, as found entering the evaporator, is not great. But when the equipment was examined after the test, deposits of copper were found in the bottom of the evaporator and in some parts of the heat exchangers. It was concluded then that the accumulation of copper in the equipment after several hours of operation resulted in severe galvanic corrosion of the aluminum heat exchangers. It was assumed that the evaporating surfaces were not pitted due to the protection of the evaporator scale formed on the evaporator tubes.

## Engineering Test Unit

A second distillation unit was designed and fabricated to take advantage of the information gained from testing the experimental unit on sea water. The major differences between the two models were the exclusion of all copper from contact with the feed water system and tube and shell heat exchangers were used instead of the concentric tube type. This all aluminum distillation unit followed conventional vapor compression distillation design with only modifications made necessary by the use of aluminum (Figures 1 and 2). A special lightweight aluminum skid was fabricated for this application and a lightweight aluminum

About  
the  
Author



RICHARD J. GAINNEY is Chief of the Water Supply Section, Sanitary Sciences Branch, USA Engineer Research and Development Laboratories, Fort Belvoir, Virginia. He has been engaged in research and development of military water supply equipment, including water purification and sea water desalting equipment, since 1941.

## Abstract

Tests of 2000 hours duration were made to determine the suitability of aluminum as a cupro-nickel substitute in the fabrication of military sea water distillation equipment. It was found that with careful design and the elimination of copper alloys from the system, aluminum heat exchangers showed satisfactory corrosion resistance under tests conditions. Data reported include sources of copper contamination in system, alkalinity of sea water at Wrightsville Beach and Dayton Beach test areas, plus analyses (chlorides, copper, aluminum) of sea water, compressed steam, distilled water and blowdown. 7.6.8, 6.4.2, 4.6.11

and canvas canopy was used to protect the equipment from the weather. The unit weighed 2800 pounds and was rated at 125 gallons per hour.

The combination evaporator-condenser provided 282 sq ft of heat exchanger surface and was fabricated of 3003 and 6061 aluminum alloys. The tubes and shell were 3003, Alclad on the sea water side only and the 3/4-inch tube sheets were 6061, Alclad both sides.

The heat exchangers were of the conventional one-pass, tube and shell type and were arranged in such a manner that sea water and brine flowed through the tubes and only distilled water flowed through the shells. The heat exchanger tubes, fabricated also of 3003 Alclad inside, were held to a small size, 1/4 inch OD, in order to provide sufficient velocity of flow to prohibit settling of any corrosion products. A vent condenser and engine oil heat exchanger of similar design were also provided. A water cooled, 4 cylinder gasoline engine was provided as a power source. The engine cooling system was connected to a feed water to engine water heat exchanger fabricated of the same material as the other heat exchangers. The engine was not considered a source of corrosion because the cooling system was a closed cycle.

TABLE 1—Sources of Copper Contamination

Sample	Copper, mg/l
Sea water, dip sample.....	0.00
Feed tank, after raw water pump...	0.10
After feed pump.....	0.60
Blowdown from evaporator.....	0.05
Distillate.....	0.15

\* Submitted for publication March 14, 1961.



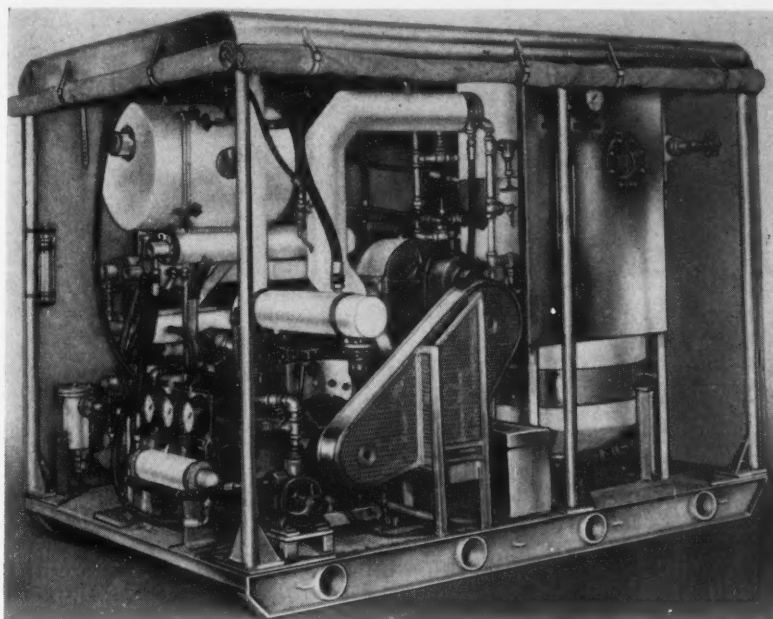


Figure 1—Experimental 125 GPH vapor compression aluminum sea water distillation unit.

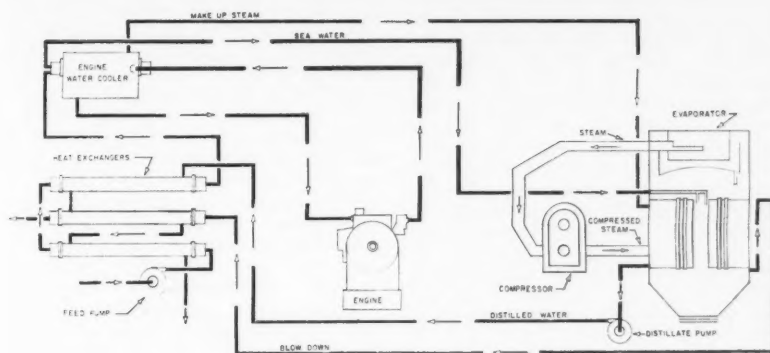


Figure 2—Schematic flow of distillation unit shown in Figure 1.

The sea water feed pump was of the positive displacement with Type 316 stainless steel pump body, neoprene impeller, and fluorocarbon packing. The distilled water pump was a turbine-type pump also fabricated of Type 316 stainless steel.

The steam compressor provided the only important source of copper contamination in the distillation unit. An effort was made to obtain a suitable compressor fabricated of non-copper materials but none was immediately available. A review of the galvanic series indicated that a sacrificial aluminum element might remove copper from the compressor discharge steam, even though the quantities involved were extremely small, less than 1 mg/l. Prior experience had shown that this small amount of copper might result in pitting of the exterior surfaces of the evaporator tubes. Accordingly, a small chamber fitted with an expendable alloy 5056 aluminum mesh was installed in the steam discharge line to evaluate the possibility of removing

any copper picked up by the steam from the bronze steam compressor.

#### First Test On Sea Water

Through the courtesy and cooperation of the International Nickel Company, a test area was made available at their Harbor Island Marine Test Laboratory, Wrightsville Beach, N. C. The equipment was transported to Wrightsville Beach and put into operation within 100 feet of the shore line. The aluminum distillation unit was operated 24 hours per day, six days per week on full strength sea water. The evaporator scale was removed approximately every 100 hours with citric acid in order to clean evaporator tubes exposed to the boiling brine. Approximately 20 pounds of granular citric acid were added directly to the evaporator through the drain opening while the equipment was in full operation. When the evaporator blowdown indicated that no more acid was being neutralized by the scale, which took about 15 minutes, the evaporator was

TABLE 2—Average Analyses of Samples Taken During Sea Water Tests at Wrightsville Beach, N. C.

Source	Amount, mg/l
<b>Sea Water:</b>	
Alkalinity.....	114
Chlorides.....	17,989
Copper.....	0.02
Aluminum.....	0.05
<b>Compressed Steam:</b>	
Copper.....	0.35
Aluminum.....	0.27
<b>Distilled Water:</b>	
Alkalinity.....	5.3
Chlorides.....	12.2
Copper.....	0.006
Aluminum.....	0.06
<b>Blowdown:</b>	
Alkalinity.....	91
Chlorides.....	51,691
Copper.....	0.03
Aluminum.....	0.27

TABLE 3—Average Analyses of Samples Taken During Sea Water Tests at Daytona Beach, Florida

Source	Amount, mg/l
<b>Sea Water:</b>	
Alkalinity.....	129
Chlorides.....	19,493
Copper.....	0.023
Aluminum.....	0.014
<b>Compressed Steam:</b>	
Copper.....	0.42
Aluminum.....	0.13
<b>Distilled Water:</b>	
Alkalinity.....	7.7
Chlorides.....	10.7
Copper.....	0.008
Aluminum.....	0.012
<b>Blowdown:</b>	
Alkalinity.....	108
Chlorides.....	48,592
Copper.....	0.03
Aluminum.....	0.23

drained, flushed, and put back into operation. No attempt was made to remove any scale from the heat exchangers during the test but the blowdown heat exchanger was subjected to the citric acid because some of the hot brine containing the acid drained through this heat exchanger during the descaling operation.

Operating data were collected hourly during the test and chemical analyses were made of the feed water, distilled water, brine, and compressor discharge steam one or more times per day. The analyses of the compressor discharge steam were made to determine the amount of copper picked up by the steam passing through the bronze compressor.

All analyses were made in accordance with the APHA "Standard Methods for the Examination of Water, Sewage, and Industrial Wastes," except that a direct reading colorimeter was used for colorimetric determinations of copper and aluminum. The averages of many analyses are shown in Table 2.

During the operation of the equipment it was found necessary to replace the expendable aluminum mesh in the steam line each 50 hours. At the end of this 50 hour period the aluminum mesh had deteriorated to a considerable extent in certain spots. The success of this method



of removing small amounts of copper from the steam is illustrated by noting that the amount of copper in the steam discharge averaged 0.35 mg/l but only a few samples of distilled water contained any measurable amount of copper and the average was 0.006 mg/l. If the aluminum mesh had not removed the copper from the steam, the distilled water would have contained the 0.35 mg/l found in the steam from the compressor.

After 713 hours of operation on sea water the equipment was returned to the Laboratories and disassembled for inspection. The evaporator tubes were clean and bright with no evidence of corrosion. The heat exchangers showed no pitting or other type of corrosion and an almost complete absence of any scale. The blowdown heat exchanger, which was subjected to high concentrations of citric acid during the descaling operations, was also free of any evidence of corrosion.

The only corrosion noted within the equipment was on the evaporator tube sheet within the areas close to and under the flange gaskets. In these areas the corrosion was not present in small pits as might be expected, but was in the form of depressions in the cladding of the  $\frac{3}{4}$  inch Alclad tube sheet. Apparently, the cladding acted as a sacrificial material which protected the core metal of the tube sheet. The corrosion in this area was attributed to "poultice type" action of the stagnant water under the gasket.

The only other corrosion in the unit was noted in the short piece of aluminum pipe between the bronze steam compressor and the copper removal device. No corrosion was found down stream from the expendable aluminum mesh.

#### Second Test On Sea Water

The equipment was reassembled without any repairs except for the replacement of the evaporator gaskets. The Office of Saline Water, Department of Interior, provided the use of part of their Solar Distillation Test Station located near Daytona Beach, Florida for an extension of the test on sea water. The sea water here was full-strength and differed from the sea water at Wrightsville Beach, N. C., only in that it contained a considerable amount of organic material and marine organisms.

The equipment was again operated on a 24-hour per day, six days per week basis with hourly operating data collected and chemical analyses performed at least once per day. A summary of the chemical analyses (Table 3) shows that the results were very similar to results obtained at Wrightsville Beach. Here again the significant figures are the 0.42 mg/l of copper in the steam compressor discharge and only 0.008 mg/l average copper in the distillate. This information again shows that practically all copper introduced into the steam by the bronze compressor was removed by the aluminum mesh before the steam was condensed in the combination evaporator-condenser.

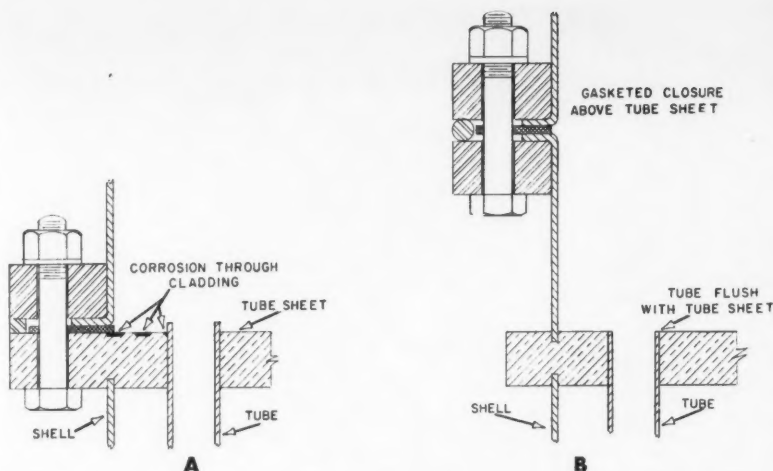


Figure 3—Corrosion of cladding on an evaporator tube sheet near closure shown in A; method of preventing such corrosion shown in B.

#### Final Inspection

After 1,469 hours of operation at Daytona Beach, or a total of 2,182 hours on sea water, the unit was disassembled again and inspected for evidence of corrosion. The heat exchanger tubes and the evaporator tubes were free of any signs of corrosion. The corrosion of the aluminum cladding on the evaporator tube sheets in the areas close to the evaporator gasket had expanded horizontally but had not penetrated into the 6061 tube sheet core alloy (Figure 3A). The end of the evaporator tubes were not cutoff flush with the sheet but extended  $\frac{1}{4}$  inch beyond. A few spots of corrosion were noted in the area where the tube sheet contacted the outside of the evaporator tubes. This corrosion was restricted to the tube sheet alone and did not penetrate into the core metal.

This final inspection showed one additional area of corrosion. The circulating engine cooling water entered the upper part of a flash tank and ran over part of aluminum tubes containing the flow of sea water. The outside of these tubes, where the full flow of engine cooling water impinged on outside surface were severely eroded and pitted. The tubes were in good condition where the engine cooling water did not drop directly on the surface. It is believed that relocating the engine cooling water inlet so that the water will not hit the tubes directly will eliminate this condition.

#### Future Work

The results of this investigation showed that with proper design and careful selection of alloys, an aluminum sea water distillation unit for military use is feasible. It is believed that such equipment can be operated on sea water for several thousand hours with little corrosion difficulties. A review of past uses of such equipment shows that portable sea water distillation units will not be used indefinitely because of the mechanical failure of such components as the engine, pumps, and steam compressor.

A new aluminum sea water distillation unit is now being designed and fabricated

which will be compact. It will be mounted on a trailer, and also will be suitable for helicopter lift. The steam compressor will be a new type with an aluminum housing and Ni-Cast rotor which will eliminate the need for the expendable aluminum mesh for removing copper from the steam. The gasketed evaporator closure will be raised three inches above the upper tube sheet and the evaporator tubes will be cut off flush with the evaporator tube sheet (Figure 3B). By this means, the corrosion of the cladding at the edge of the tube sheet will be eliminated or considerably reduced. This unit will be lighter than existing equipment, have greater capacity, and will be constructed of materials in abundant supply.

#### Summary

Nickel and copper alloys have been used by the military services for sea water distillation equipment for many years. In a search for alternate materials that may become necessary in the event of extensive military mobilization, the Corps of Engineers studied the use of aluminum for this purpose. A 2,200-hour test of equipment demonstrated that aluminum can be used for fabrication of lightweight, transportable, sea water distillation equipment required by the military for tactical use. The study revealed that earlier corrosion difficulties with aluminum were caused by the presence of small amounts of copper inadvertently introduced into the sea water by the use of bronze pumps and brass operating controls. Elimination of all copper alloys from the components of the equipment resulted in the satisfactory performance of heat exchangers fabricated of aluminum alloys. New equipment will now become available which will be lighter, have greater capacity, and cost less than distillation units covered by existing specifications.

#### References

1. W. F. Langelier, D. H. Caldwell, and G. F. Lindholm. Investigation of Measures to Prevent Scaling and Corrosion of Thermocompression Equipment Employed in the Distillation of Sea Water. University of California, August 1952.
2. Unpublished Report. USAERDL, 1956.



# Leakage Conductance Coating Surveys On Asphalt Mastic Coated Pipe\*

By GERALD J. PAISLEY\*

## Introduction

THERE ARE so many factors that affect the performance of coatings on underground pipe lines, that the planning of adequate tests and the proper interpretation of the results is extremely complex. It is not surprising, therefore, that experienced corrosion engineers often interpret the same experimental data in different ways. The cost of tests sufficiently extensive to warrant definite conclusions on a statistical basis would be prohibitive.

The examination of representative "in the ditch" coatings, selected from the vast network of coated pipe lines, offers an opportunity to add to the available information on coating behavior and field performance. Accordingly, it was felt that a coating leakage conductance survey on Magnolia Pipe Line Company's 335 miles of asphalt mastic coated products pipe line, supplemental to Donald E. Miltner's<sup>1</sup> report, would be of value.

This report outlines the methods of test employed in the examination during the fall of 1959, lists test results, and gives detailed information about coating failures found by inspection.

## Description

The line was built in 1941 and consists of 335 miles of 6 $\frac{3}{4}$  inch OD pipe, extending from Topeka, Kansas to Sioux Falls, South Dakota. The pipe line crosses the Kansas River just north of Topeka, the Platte River south of

## Abstract

Follow-up leakage conductance surveys were made at ten-mile intervals along 335 miles of continuous asphalt mastic coated pipe. Check points included three major river crossings. Test results were compared with data reported earlier on the same pipe by D. E. Miltner (see *Corrosion*, 9, 210 (1953) July). It was found that the overall current requirements of the 335 miles of six-inch pipe line had not increased in 18 $\frac{1}{2}$  years. A total current of 18 amperes over-protected the line to a minimum protective potential of 1.000 volt. Progressive deterioration of the coating as a whole was not evident although there was considerable deterioration in the immediate vicinity of coating discontinuities. The low mean average coating conductance reported indicated that cathodic protection had not adversely affected sound coatings during the 18 $\frac{1}{2}$  year interval. 4.5.3, 5.4.10

Omaha, and the Missouri River between Omaha and Sioux City. A nine-mile lateral lays through an industrial area and feeds a terminal at Omaha. A three-mile lateral serves Sioux City.

A light weight pipe of 14.96 pounds per foot API, Grade B, was selected for construction. This particular pipe was selected so as to allow an adequate factor of safety for the normal range of operating pressures, and yet provide for a maximum economy in overall investment costs. For the single line under the Kansas River and the looped Platte and Missouri River crossings, a 25.03 pound per foot pipe was used.

Pairs of test leads were installed during construction at intervals along the pipe line. The test lead pairs, comprised

of No. 10 solid copper wire, were spaced one hundred feet apart and terminated in a junction box above ground. These test leads served for measurement of current flow and potential of the pipe.

A one-half inch thick asphalt mastic pipe coating was used throughout. The coating was applied to the pipe at five railhead plants located near Holton, Kansas, Blair and Brock, Nebraska, Brownville, Iowa, and Canton, South Dakota. The basic coating composition is listed in Table 1.

Immediately following construction of the line, four rectifiers were installed near the three major river crossings and the Omaha lateral. A fifth rectifier was added in 1946 to complete cathodic protection on approximately 90 percent of the line. The pipe in the remainder of the line was electrically insulated at block valves. The coating on this portion of the line was not subjected to cathodic protection until 1951 when a sixth rectifier was added giving cathodic protection on the entire line. Minimum pipe to soil potentials of 1.000 volt (CuSO<sub>4</sub> electrode reference) were maintained throughout with estimated maximum protective potentials of 3.000 volts at the rectifier stations.

The existing rectifier locations, original current output, and 1960 current output are listed in Table 2. The rectifier cur-

\*Submitted for publication February 23, 1961. A paper presented at the 17th Annual Conference, National Association of Corrosion Engineers, Buffalo, New York, March 13-17, 1961.

\*Corrosion engineer, Magnolia Pipe Line Co., Dallas, Texas.

TABLE 1  
Basic Composition of Asphalt Mastic

Component	Percent By Weight
Asphalt.....	12-14
Asbestos Fiber.....	1
Limestone Dust, Approximately.....	24
Sand.....	61-63

TABLE 2—Cathodic Protection Stations

Location of Rectifier Stations, Miles	1941 Current Output (Amperes)	1960 Current Output (Amperes)
2.37.....	4	2
60.84*.....	5	5
148.59.....	7	3
164.37.....	7	3
214.51.....	5	4
309.50**.....	..	1
Total.....	23	18

\* Installed in 1946.

\*\* Installed in 1951.

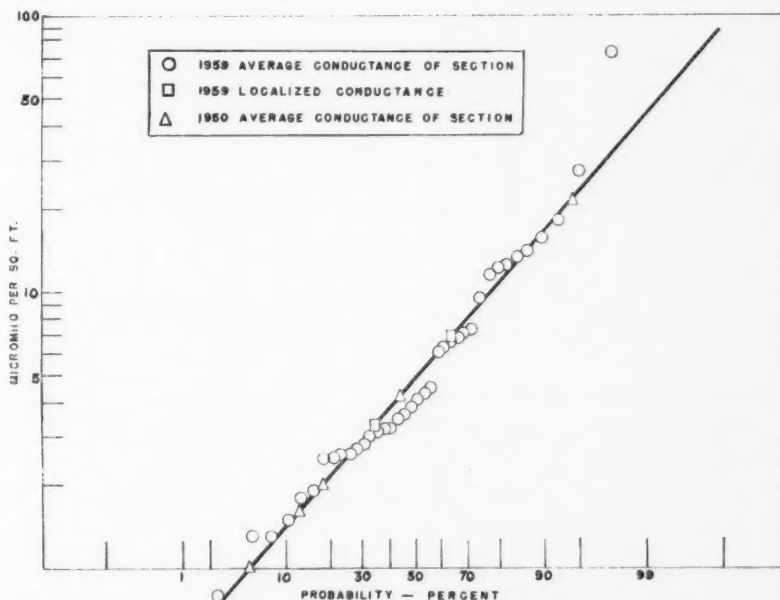


Figure 1—Probability distribution of coating conductances.



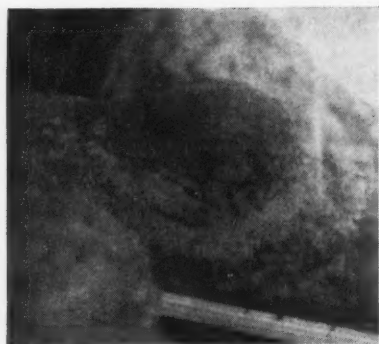


Figure 2—Pipeline coating discontinuity occurring in the flat bottom lands of the Missouri River. Soil resistivity was 1000 ohm-cm. The cemented soil lump was 5 inches in diameter and 3 inches thick.

rents are averages of all readings recorded during the years listed. All current values were recorded from the panel meters in the rectifiers. These meters, when new, had an accuracy within 2 percent.

The terrain along the pipe line was generally rolling, with poor surface drainage largely confined to river bottoms. The land was highly developed and mostly under cultivation, with little acreage permanently set apart for pasture. The soil resistivity along the line varied from 300 to 10,000 ohm-centimeters.

#### Methods of Examination

1. Coating conductance measurements were made over the entire pipe line at distances of approximately ten miles. An AC operated current interrupter was inserted in the negative DC leg of a rectifier to switch the DC current off and on at regular intervals. The change in pipe to soil potential was determined at the ends of each section. Accordingly, line current readings were taken at the same time and the change in line current determined. All measurements taken, including determination of line currents and calculations, were made in accordance with NACE Technical Unit Committee T-2D Report on Standardization of Procedures for Measuring Pipe Coating Leakage Conductance.<sup>2</sup>

2. Two known holidays found by Miltner<sup>1</sup> but left undisturbed, were excavated. Two locations, randomly selected, in the bottom lands of the Missouri River were excavated and coating conductance determined by using a cotton outing flannel pad and a wire screen wrapped around the coated pipe, as described in National Bureau of Standards Circular 579.<sup>3</sup>

#### Presentation of Data and Discussion

Coating conductance measurements were made on 38 pipe line sections during August and September, 1959. The average line section was approximately ten miles long. These conductance values and the mean average soil resistivity of each section are tabulated in Table 3 as are the coating conductance and coating discontinuity data taken in 1950 by Miltner.<sup>1</sup> The 1950 conductance values are too few in number to make a valid com-

TABLE 3—Coating Conductance Values

Sta. to Sta.	Span (Miles)	Coating Conductance, micro-ohm/ft <sup>2</sup>		Avg. Soil Resistivity, ohm-cm <sup>3</sup>	1950 Holidays in Section	Location
		1959	1950			
0.00 0.56	0.56 3.90	0.56 3.34	3.2 9.8	1500 1900	0 0	MP-2 Rectifier at Kansas River
4.78 14.84 23.56	14.84 23.56 33.79	10.06 8.72 10.23	27.7 4.3 2.5	21.3 2.0 4.2	1533 1440 1880	
33.79 44.78 53.81 60.84 64.02	44.78 53.81 60.84 64.02 75.31	10.99 9.03 7.03 3.18 11.29	4.1 3.5 3.2 1.5 5.0	1660 1450 2040 1460 1380	0 3 11 3 1	
75.31 86.89 95.54 104.35 133.11	86.89 95.54 104.35 133.11 145.56	11.58 8.65 4.12 28.76 12.45	6.6 3.1 7.1 2.7 3.8	740 795 810 940 990	0 0 0 7 5	
145.56 156.90 164.52 173.56 180.48	156.90 163.50 173.56 180.48 190.67	10.55 6.60 9.04 6.92 10.19	18.1 12.6 2.5 11.6 13.5	2320 1060 1275 1270 795	2** 1 0 3 4	Platte River MP-148 Rectifier MP-164 Rectifier
190.67 200.47 211.93 213.32 218.67 228.08	200.47 211.93 213.32 228.08 243.58	9.80 11.46 1.39 10.41 15.54	12.2 15.7 72.6 7.3 3.0	685 860 1225 1050 790	14 15 1** 0 3	
237.77 243.58 243.58 244.61 248.51	244.61 248.51 248.51 262.83	1.03 3.90 14.32	3.29* 14.0 6.92* 6.1 1.8	1875 3155 3595	0 0 0	—Includes Partial Short @ Pump Station
262.83 270.46 277.76 281.79 288.51	270.46 277.76 281.79 288.51 307.41	7.63 6.22 5.11 6.72 18.90	2.8 0.8 6.8 1.3 1.3	2480 2990 4590 4525 3845	0 0 0 0 0	
291.45 298.33	298.33 304.21	6.88 5.88	1.6 1.0	0 0	0 0	
312.66	319.99	7.33	2.6	4132	0	
319.99 322.24	322.24 324.18	2.25 11.94	1.9 3.6	2180 6135	0 0	
Omaha Lateral S. City Lateral	9.44 3.06	6.3 2.6	...	1210 2580	0 0	MP-310 Rectifier
Mean			4.9	1600		

\* Localized test.

\*\* No data on rivers.

parison for the entire line, although it can be seen that the line sections measured in 1950 and 1959 yield comparable results.

Kulman<sup>4</sup> has shown that probability distribution of coating conductances conforms to the logarithmic normal probability law. The probability techniques used here, and by Kulman, are those discussed by Scott.<sup>5</sup> Accordingly, the 1959 coating conductances listed in Table 3 plot a reasonably straight line on logarithmic probability paper. The 1950 data are shown in Figure 1 as triangles. The two localized 1959 tests are plotted as rectangles on the curve. Kulman<sup>4</sup> suggests that data which do not fall on or near the straight line indicate a disturbing factor that may be the result of an error in the measurement, an accidental contact between the pipe and another metallic structure, or some other cause which can be investigated and isolated.

The largest value plotted in Figure 1 is the 1.39 mile segment across the Missouri River. During the spring of 1951, the Missouri River reached record flood levels. The flood was of such magnitude that two 12-inch pipe line crossings belonging to another pipe line company and located a few hundred feet upstream were washed out. Following the flood, an inspection showed that approximately 20

feet of Magnolia Pipe Line Company's submerged crossing was suspended across a new channel in the river. It is probable that the high average conductance of the 1.39 mile segment was the result of damaged coating caused by debris tumbling along the river bottom and striking the pipe.

All of the coating discontinuities reported by Miltner<sup>1</sup> were not excavated for inspection in 1950. But two of these discontinuities, which were classified by Miltner as medium signal strength, were located and excavated. At both locations the discontinuities appeared to have been enlarged in area. The cemented soil lumps were extremely hard and proved difficult to fracture with a hammer and chisel. The coating adhered to the soil lumps and appeared to have little or no bond to the pipe. The remaining coating under the lump, at these locations, had softened to the extent that a hole could be dug in the mastic with the corner of a putty knife.

The discontinuity found at Mile Post 189.79 and the pipe under the soil lump are shown in Figures 2 and 3. Only a thin layer of the surface coating remained under the cemented soil lump at Mile Post 158.16 (see Figure 4). It was also found that the discontinuity exceeded the length of the four-foot bell-



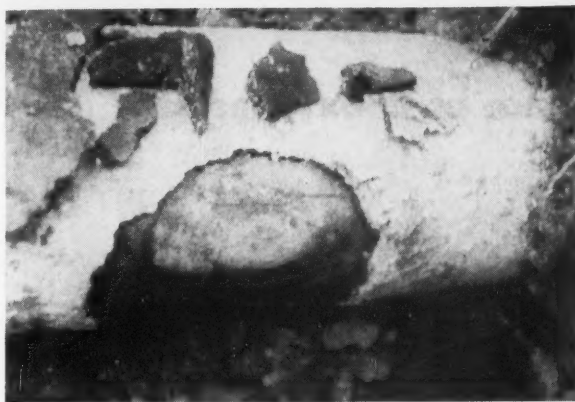


Figure 3—Pipe surface under lump in Figure 2. The pipe was rusted considerably, although no pitting was observed. Note the circular pattern of rust stains.

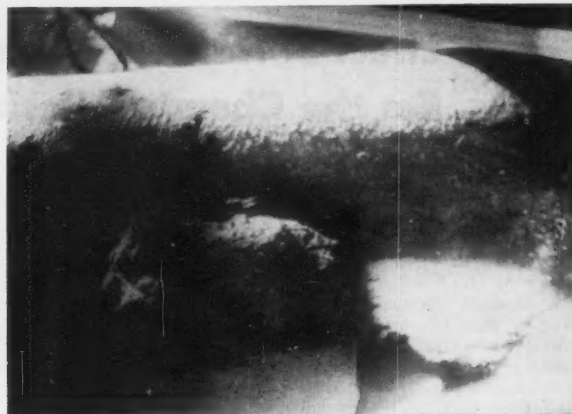


Figure 4—Discontinuity on bottom of pipe (photographed with the aid of a mirror). Soil lump was 4 inches thick and 5 inches wide. The length extended beyond the bell-hole.

hole. It is certain that this discontinuity would have been classified as a major break in the 1950 survey and opened for inspection at that time. The indication is that the coating is progressively disintegrating at the holidays.

The pipe surface was rusted to a considerable extent at both locations, although no pitting of the pipe was observed. Miltner reported traces of rust at some of the discontinuities excavated in 1950, but considered it probable that the corrosion products were due to oxidation after the pipe was exposed.

Scott<sup>6</sup> reports: "Passivation of iron occurs generally in the pH range 8.5 to 12.5 in the absence of anions like chloride and sulfate. However, if the current density is such that the pH exceeds this limit, the passivating film will be dissolved by the hydroxide ion and under the potential afforded by the oxygen, iron will dissolve to form soluble ferrites or ferrates which ultimately precipitate as hydrated ferric oxide." It is highly probable that the corrosion products observed in 1959 were produced by cathodic protection currents returning to the pipe through the coating discontinuity.

At Mile Post 4.1, one thousand feet of pipe was excavated and inspected in conjunction with a newly constructed crossing under the Kansas River. The inspection revealed two coating blisters ap-

proximately four inches in diameter and separated from the pipe approximately three-eighths of an inch at their centers. The original whitewash was intact throughout, and there was no cemented soil at either blister. The "blistered" coating was one-half inch thick and had no visible cracks or pinholes. The bond between coating and pipe was good everywhere tested, including the areas adjacent to the blisters. The dry pipe surface under the blister was rusted considerably, although no pitting was observed. It is not known if these blisters were caused by some mishap at the time of construction, or the result of cathodic protection currents.

#### Summary

1. The overall current requirements of the 335 miles of six-inch pipe line have not increased in 18½ years. (See Table 2.) A total of 18 amperes over-protects the pipe line to a minimum protective potential of 1.000 volts. All coating conductance data measurements collected during 1950 and 1959 fall within the same range and conform to the probability law. Progressive deterioration of this coating as a whole is not evident.

2. The rate of discontinuities found by Miltner<sup>1</sup> was one per four miles. This exceedingly low rate, and the low coat-

ing leakage conductance found in this survey, substantiates the high quality of coating found in both examinations.

3. The coating appears to be progressively deteriorating in the immediate vicinity of the coating discontinuities.

4. The low mean average coating conductance (4.9 micro-mho/ft<sup>2</sup>) shows that cathodic protection has not appreciably affected the sound coating as a whole for at least 18½ years.

#### Acknowledgment

The author acknowledges and appreciates the cooperation and assistance afforded by Dr. Gordon N. Scott throughout this investigation.

#### References

1. D. E. Miltner. Examination of 335 Miles of Asphalt Mastic Coated Pipe. *Corrosion*, 9, 210 (1953) July.
2. Methods for Measuring Leakage Conductance of Coating on Buried or Submerged Pipe Lines. *Corrosion*, 13, 803t-805t (1957) December.
3. Underground Corrosion. National Bureau of Standards, Circular 519, Appendix 6, page 221.
4. F. E. Kulman. Coating Resistance Conforms to Probability Law. *Corrosion*, 13, 553t (1957) September.
5. G. N. Scott. The Distribution of Soil Conductivities and Some Consequences. *Corrosion*, 14, 396t (1958) August.
6. G. N. Scott. Comments on the Paper "Determining the Effect of Formulation on Physical Properties of Asphalt Mastic Coatings" by Lyle R. Sheppard. *Corrosion*, 17, 167t-170t (1961) Apr.

Any discussion of this article not published above  
will appear in June, 1962 issue



# Effect of Hardener Composition On the Chemical Resistance of Epoxy Resins\*

By FRANK E. PSCHORR\*

## Introduction

A VARIETY of hardeners can be used in curing epoxy resins. The type of hardener selected is an important factor in determining the chemical resistance of the cured systems. With the varying reaction mechanisms ensuing with these hardeners, chemical resistance varies considerably.

## Experimental Procedure

### Materials Evaluated

A conventional liquid epoxy resin, having a viscosity of 9000 cps (25 C) and an epoxy value of 0.54 eq./100 gm, was cured with five different hardeners. These materials are shown in Table 1.

### Systems Evaluated

Table 2 lists the hardener type and concentration used in this study. In addition, the curing cycles used as well as the initial flexural strengths obtained with the various systems are listed.

Castings were prepared for each system. After the castings were cured, a sufficient number of 4 inch by 1 inch by 1/8 inch specimens were cut from each sheet. Flexural strengths were then determined for each system according to ASTM D790-58T. These strengths were determined both before and after 6-months immersion (at 25 C) in various chemical reagents. Initial flexural strengths were determined using five specimens for each system. Flexural strengths after immersion were determined using three specimens for each system evaluated.

## Discussion

### Salt Resistance

After 6-months immersion in 10 percent and 25 percent sodium chloride, as well as 10 percent sodium bisulfite, the following results were obtained: The diaminodiphenyl sulfone cured system showed the most stability followed closely by the boron trifluoride monoethylamine complex system. Nadic methyl anhydride showed better resistance to the salts tested than the phthalic anhydride system. The Hardener 956 system was the least resistant.

Results obtained by flexural-strength measurements do not necessarily agree with percent weight change. Systems showing the largest amount of weight

change do not show the greatest change in flexural strength. For example, the diaminodiphenyl sulfone system showed a weight increase of 2.6 percent after 6 months in 10 percent sodium bisulfite, but yielded no change in flexural strength. On the other hand, both anhydride cured systems showed a weight change of only 0.9 percent but a flexural strength change of +9.3 (phthalic anhydride) and +15 (nadid methyl anhydride) when tested under the same conditions. These results are shown in Figure 1.

### Acid Resistance

Immersion in 3 percent, 10 percent and 30 percent sulfuric acid was best resisted by the diaminodiphenyl sulfone system followed closely by both anhydride-cured systems.

The nadic methyl anhydride system showed the best resistance to 10 percent nitric acid. In addition, this system exhibited the best over-all acid resistance. The Hardener 956 system yielded the poorest acid resistance.

Here again weight change could not be directly correlated with percent flexural strength change. Diaminodiphenyl sulfone yielded no change in flexural strength after 6-months immersion in 10 percent sulfuric acid, but did show a weight change of 2.5 percent. The phthalic anhydride system showed a weight change of only 0.84 percent after 6 months in 10 percent nitric acid but yielded a 26 percent decrease in flexural strength. See Figure 2.

## Abstract

One of the factors influencing the chemical resistance of epoxy resin is the hardener used in their curing. To demonstrate this, three chemically different types of hardeners (anhydride, amine, boron fluoride complex) were used to cure a conventional liquid epoxy resin. All systems were checked for changes in flexural strength after a six-month immersion period in various chemicals at room temperature. Media in which tests were made include sodium chloride, sodium bisulfite, sulfuric acid, hydrochloric acid, nitric acid, glacial acetic acid, caustic soda, sodium carbonate, ammonia solution, and four weak organic solvents. In addition, samples were also placed in water at room temperature as well as boiling water for a six-month immersion period.

Diaminodiphenyl sulfone gave resins the best over-all chemical resistance. Weak solvents, such as hydrocarbons, alcohols or glycols, affected all systems only slightly. Anhydride-cured systems exhibited better resistance to diluted acids while amine-cured systems showed better resistance to diluted bases.

6.6.8

### Resistance to Bases

After immersion in 10 percent and 25 percent caustic soda, 25 percent sodium carbonate as well as 25 percent ammonia, the diaminodiphenyl sulfone yielded the most resistant system. The next best was the boron trifluoride monoethylamine complex system. Phthalic anhydride was the poorest followed by the nadic methyl anhydride cured system. Figure 3 illustrates these results.

### Resistance to Weak Organic Solvents

With regard to resistance to weak organic solvents, such as gasoline, benzene, ethyl alcohol, and ethylene glycol, all systems performed well. Ethyl alcohol

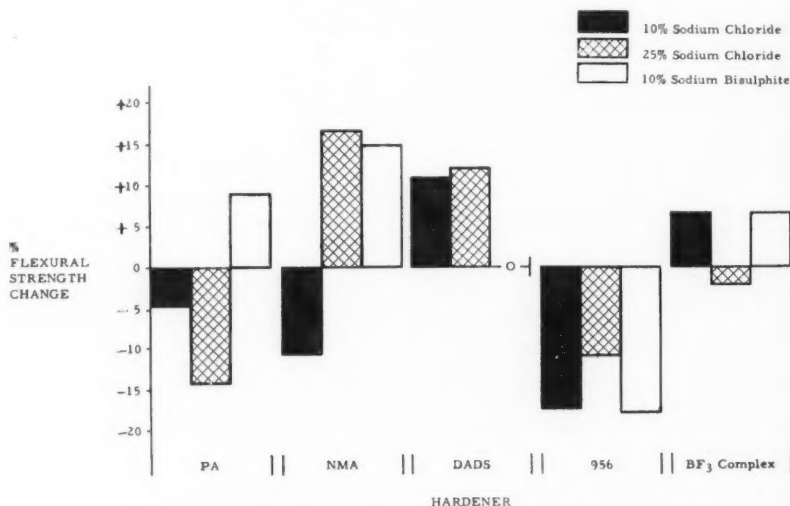


Figure 1—Percent flexural strength change after six months immersion in salts.

\*Submitted for publication March 27, 1960. A paper presented at the 17th Annual Conference, National Association of Corrosion Engineers, Buffalo, New York, March 13-17, 1961.

\*Manager of Technical Service and Process Development, CIBA Products Corp., Fair Lawn, New Jersey.



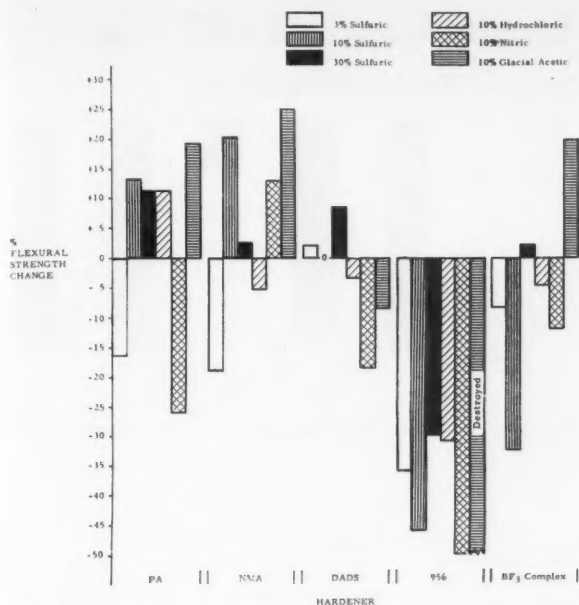


Figure 2—Percent flexural strength change after six months immersion in acids.

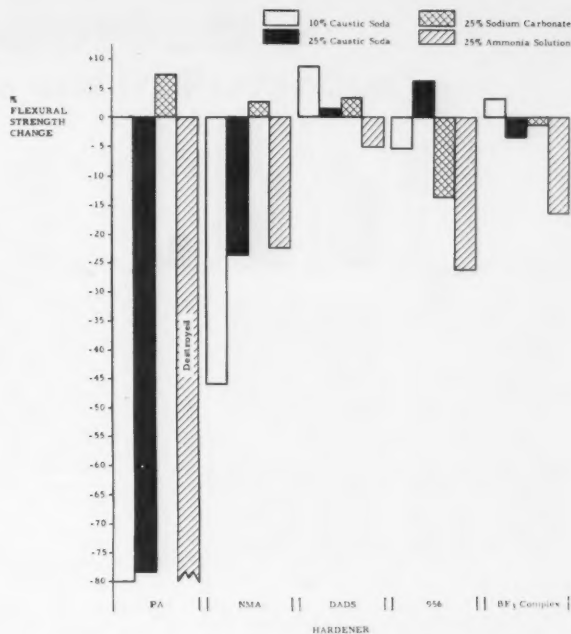


Figure 3—Percent flexural strength change after six months immersion in brines.

TABLE 1—Resin and Hardeners Used in Testing

<b>Epoxy Resin:</b>	
Araldite 6005—unmodified liquid epoxy resin; viscosity = 9000 cps., epoxy value = 0.54 eq./100 gm.	
<b>Hardeners:</b>	
901—Phthalic anhydride (PA)	
906—Nadic methyl anhydride (NMA)	
Diaminodiphenyl sulfone (DADS)	
956—Amine—type safety hardener	
Boron trifluoride monoethylamine (BF <sub>3</sub> Complex)	
<b>Accelerator:</b>	
DMP-30—2, 4, 6, Tri (dimethylaminomethyl) phenol	

appeared to have the most noticeable effect upon the Hardener 956 system while benzene had the most noticeable effect upon the phthalic anhydride system. This is illustrated in Figure 4.

#### Resistance to Water

After 6 months immersion in water at 25 C, both the phthalic anhydride and diaminodiphenyl sulfone systems appeared quite resistant. However, when testing all systems after 6 months in boiling water, only the diaminodiphenyl sulfone system yielded the best results. It is also interesting to note that this system resulted in best over-all chemical resistance (see Figure 5).

#### Conclusion

Comparative tests have demonstrated that the type of hardener used to cure an epoxy resin will have a substantial effect upon its chemical resistance. The best over-all chemical resistance was obtained with diaminodiphenyl sulfone. This hardener also yielded a cured epoxy system with superior resistance to boiling

TABLE 2—Epoxy Curing Systems Evaluated

Hardener Type	Hardener Concentration*	Curing Conditions	Curing Mechanism	Initial Flexural Strength, psi
Anhydride	65 phr** phthalic anhydride	24 hrs. at 140 C	esterification + etherification	19,750
	80 phr nadic methyl anhydride	12 hrs. at 120 C + 12 hrs. at 180 C		20,400
	+2 phr DMP-30	12 hrs. at 250 C		
Amine	35 phr diaminodiphenyl sulfone	6 hrs. at 135 C + 12 hrs. at 180 C	etherification + polyoxyamines	13,800
	25 phr hardener 956	24 hrs. at 25 C + 24 hrs. at 40 C		15,600
	4 phr boron trifluoride monoethylamine	6 hrs. at 80 C + 6 hrs. at 120 C + 12 hrs. at 150 C	essentially etherification	14,800

\* Using liquid epoxy resin with an epoxy value of 0.54 eq./100 gm.  
\*\* Parts per hundred parts of resin.

water. Nadic methyl anhydride yielded a more chemical-resistant system than did phthalic anhydride.

#### Acknowledgment

The author wishes to thank Dr. H. Brüscheiler and others of the Applications Research Laboratory at CIBA Limited, Basle, Switzerland, for their aid in preparing the data presented in this paper.

#### DISCUSSION

Questions by Henry Hasbrouck, Hamburg, New York:

1. Were test samples castings or reinforced?

2. What is the effect on test results of lack of proper control of post curing? For example, what would be the effects

in a field application where no heating facilities are available?

3. To what do you attribute instances of increase in flexural strength after testing?

#### Replies by Frank E. Pschorr:

1. 1/8-inch sheet castings were prepared for each system that was evaluated.

2. Post curing is very important to obtain optimum chemical resistance. In a field application where no heating facilities are available, it will not be possible to obtain a cured epoxy resin with maximum chemical resistance. But inasmuch as chemical resistance required will depend upon the application, a post cure may not be necessary.

3. We have observed that chemical solutions sometimes dissolve low molecular



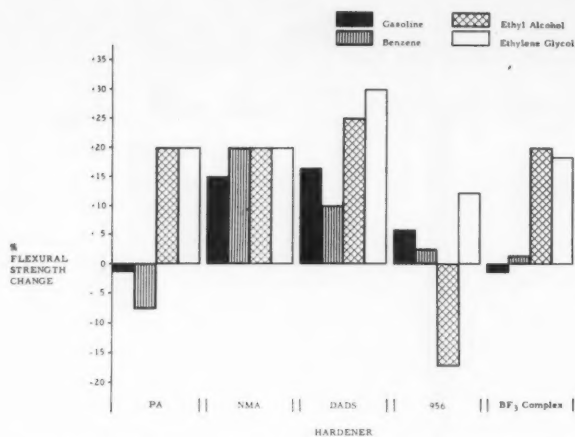


Figure 4—Percent flexural strength change after six months immersion in weak organic solvents.

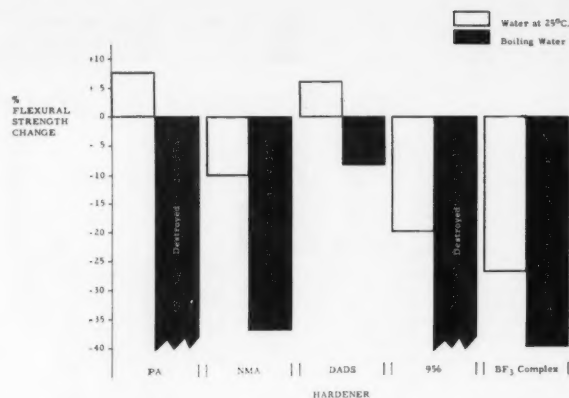


Figure 5—Percent flexural strength change after six months immersion in water.

weight fractions and we believe this may be partially the reason for flexural strength increase. On the other hand, higher molecular weight fractions can actually absorb a chemical solution. This then could act as a plasticizer and result in a resin with a higher flexural strength after immersion. Both of these phenom-

ena could be an explanation for the flexural strength increase observed in some of these chemical immersion tests.

**Question by Ignatius Metil, 99 Downing, Buffalo 20, New York:**

What type of curing agent would yield the highest heat distortion point when cured at  $77 \pm 5$  F?

**Reply by Frank E. Pschorr:**

Polyfunctional aliphatic amines, such as triethylene or diethylenetriamine, would be the type of curing agent yielding the highest heat distortion point when curing conventional epoxy resins at this temperature.

Any discussion of this article not published above will appear in June, 1962 issue

### Technical Papers on Corrosion Welcomed

Authors of technical papers on corrosion are invited to submit them for review without invitation to the Editor of Corrosion. Write for "Guide for the Preparation and Presentation of Papers" sent free on request to prospective authors.



# The Electrochemical Approach To Cavitation Damage and Its Prevention\*

By H. S. PREISER and B. H. TYTELL

## Introduction

**T**HE FORMATION of vapor cavities (boiling) in a turbulent, vibrating or fast flowing fluid and the subsequent collapsing of these vapor cavities (condensation) on material surfaces leads to a rapid, localized deterioration of the surface known as cavitation damage. The damage rate on metal surfaces is usually increased in corrosive fluids such as seawater or other electrolytes.

The devastating effects of cavitation have long been recognized on ships, hydraulic systems, and machinery. In ships, the phenomenon of cavitation causes damage to propellers and other appendages, induces propeller and hull vibrations, produces objectionable noises, and causes loss of propulsive efficiency. In hydraulic machinery similar effects have been observed. Cases are known where propellers on transatlantic liners had to be replaced every two trips. Recently, on one class of U.S. destroyers, considerable cavitation damage has been observed on propellers after only about 40 hours of continuous high speed operation (see Figures 1 and 2).

Cathodic protection is an effective method for reducing or arresting corrosion of a metal by making the metal a cathode in an electrolytic circuit. Cathodic protection is widely applied to pipe lines and structures buried in the soil, and to ships and equipment immersed or submerged in the sea.<sup>1</sup>

If cavitation damage is the result of an interaction between mechanical and electrochemical forces, then cathodic protection should be effective in eliminating the corrosion factor, thereby reducing the overall damage rate. The work of earlier investigators starting with Petracci in 1949 and continuing through to Plesset in 1959 confirms this concept in general.<sup>2-11</sup> However, since these investigators varied the experimental conditions, the data obtained showed little correlation and thus no unified mechanism of cavitation damage has been postulated to date. The work of these investigators is reviewed in a subsequent portion of the paper and some new data are reported which were obtained in recent experiments conducted by the authors.

Since 1952 the authors have speculated that cathodic protection techniques employing current densities in excess of those normally used would eliminate or substantially reduce cavitation damage by:

a. Suppression of the corrosion factor by

## Abstract

This paper presents a unified theory on the interrelationship between electrochemical and mechanical factors causing damage to materials subjected to cavitating environments. The ambiguous term "cavitation erosion" is rejected in favor of three modes of damage which depend on the severity of cavitation collapse forces: Cavitation Deformation or Fracture; Cavitation Fatigue; and Cavitation Corrosion. The authors describe some model propeller experiments which demonstrate Cavitation Fatigue damage and how specific cathodic protection measures reduce the damage. An extensive bibliography is appended.

3.5.3

nullifying potential differences between local anodic and cathodic areas arising from the changes to physical and chemical properties of the metal surface and the fluid environment due to the cavity collapse forces;

b. Mechanical cushioning of the cavity collapse forces by the evolution of hydrogen gas resulting from the cathodic process.

## Historical Background

Although cavitation phenomena were recognized as early as 1754 by Euler, it was not until many years later that Reynolds<sup>12</sup> in 1894 revived interest in the subject by his experiments of flowing water in a constricted tube. However, serious research into the nature and mechanism of cavitation damage was not started until 1919 by Parsons and Cook.<sup>13</sup> Since that time, numerous experiments were carried out by many workers in scientific fields of hydrodynamics and fluid mechanics, metallurgy and materials engineering, chemistry and electrochemistry, and other related disciplines. These re-

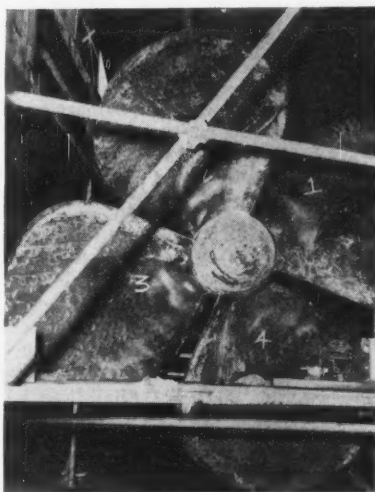


Figure 1—Cavitation damage on a destroyer propeller (port side).



Preiser



Tytell

HERMAN S. PREISER is President and Technical Director of Chemionics Engineering Laboratories, Inc., Philadelphia, Pennsylvania. He was formerly a consulting corrosion engineer in charge of cathodic protection for the Research and Development Division of the U. S. Navy Bureau of Ships. He has a BS degree from Webb Institute (1949). Mr. Preiser has been active in NACE affairs since 1948 and was Technical Program Committee Chairman for the 1959 Northeast Regional Meeting. He has contributed profusely to the corrosion literature and he holds several patents related to shipboard cathodic protection systems.

BORIS H. TYTELL is a professional engineer in the Commonwealth of Massachusetts. He was formerly a research chemist in the Chemical Laboratory of the Boston Naval Shipyard. He has been intimately concerned with marine corrosion problems since he entered government service in 1930. He received his BS in chemistry in 1921 from Brooklyn Polytechnical Institute and spent two additional years pursuing graduate studies there. He is an active member of The Electrochemical Society, National Association of Corrosion Engineers and The Society of Plastic Engineers. He is author of many articles on cathodic protection and has recently been granted a patent on a new type of anode holder.



Figure 2—Close up of propeller blade showing cavitation damage.

\*Submitted for publication January 3, 1961. A paper presented at the 17th Annual Conference, National Association of Corrosion Engineers, Buffalo, New York, March 13-17, 1961.



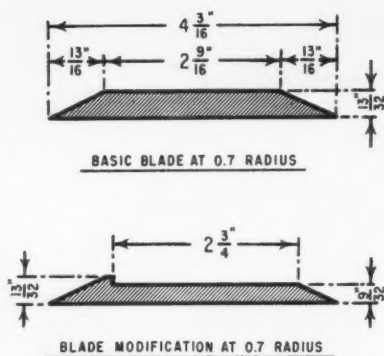


Figure 3—Basic test propeller blade.

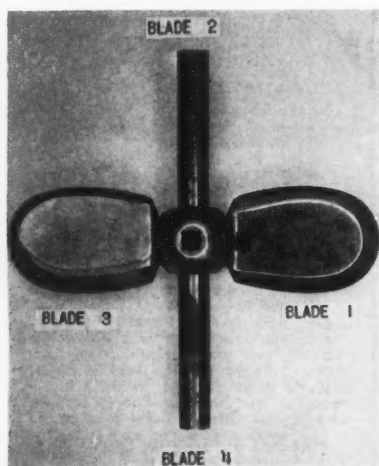


Figure 4—Multiple blade assembly used in cavitation study.

searchers laid the foundation toward a better understanding of cavitation phenomena<sup>14-18</sup> and its damaging effects to materials.<sup>19-21</sup> There is still widespread disagreement, however, as to a comprehensive general mechanism of cavitation damage.<sup>22-26</sup> An excellent review of the present knowledge on cavitation damage has been made by Dr. D. J. Godfrey<sup>27</sup> in England.

A brief summary relating the findings of many investigators referenced in Dr. Godfrey's paper is given below with some additional inclusions reporting more recent work:

Cavities form in moving fluids when conditions cause localized pressures to fall below the vapor pressure. Under certain circumstances, the cavities can collapse in the order of a millisecond with forces up to 200,000 psi. Visible damage to almost all materials is produced in a very short time when repeated cavity collapse is concentrated in a small area. Accelerated cavitation damage may be produced in the laboratory by means of venturi tubes,<sup>2, 28, 29</sup> high speed rotating discs,<sup>7, 30</sup> magnetostriction devices<sup>31</sup> and acoustic resonance devices.<sup>32</sup>

The properties of the fluid which may affect the intensity of the damage are air content, pressure, temperature, chemical composition, and inhibitive additives. Minute air particles in suspension in the

fluid aid in triggering cavitation reactions. Paradoxically, the introduction of air bubbles in cavitating fluids aids materially in preventing cavitation damage by compressibly absorbing some of the energy of the cavity collapse. The fluid pressure affects the cavitation inception in a manner that increasing the pressure decreases cavitation tendency and vice versa. Temperatures from 0 C to 50 C appear to increase cavitation damage rate, while above 50 C, the rate is progressively reduced. Cavitation damage is generally greater in the presence of electrolytes as compared to non-ionic liquids. Air and oxygen complicate the picture by increasing the damage rates in conductive fluids. Inhibitive additions generally do not alter cavitation damage when studied under accelerated laboratory conditions; however, they appear effective in practical situations where lesser cavitation intensities and frequencies are encountered.<sup>33</sup>

Ductility, hardness, ability to work harden, grain size, brittle inclusions, fatigue strength and resilience are important physical properties of materials which influence cavitation damage rate. The corrosion resistance of a metal (formation of tenacious continuous protective films) plays a significant part in resisting cavitation damage. Corrosion resistant materials which are hard and ductile or easily work hardened and also which have good fatigue strength are ordinarily superior in resisting cavitation damage. Such metals include austenitic stainless steels, aluminum nickel bronzes and titanium alloys. Non-metallic substances which are resilient and tough, such as rubber and certain plastic resins, perform better than brittle hard materials.

The idea that cavitation damage may be explained as the result of a combined mechanical (physical destruction) and chemical action (corrosion) induced by collapsing vapor cavities in moving fluids is not new.<sup>34-36</sup> However, the elusive element in developing a satisfactory mechanism for cavitation damage has been the degree that the mechanical and chemical (electrochemical) agents contribute to the damage when acting singly and in combination. Since some evidence from previous investigators has shown that under certain conditions the corrosion influence in cavitation damage could be considerable, several studies were carried out during the past decade to determine how cavitation damage is affected when the corrosion agent is eliminated by means of cathodic protection<sup>3, 5, 6, 7, 8, 37</sup> and how the total damage rate is affected by introducing hydrogen gas as part of the cathodic reaction.<sup>2, 4, 9, 10, 11, 38</sup>

#### Cavitation Test Apparatus

The variety of test equipment that has been used in the past to conduct cavitation damage studies is believed to be the primary reason for the difficulty in separating the corrosion and mechanical components of the damage. Generally, most equipment is not readily adapted for determining the degree that the mechanical and corrosion factors may be

influenced by the application of cathodic protection. The test apparatus developed for accelerated cavitation damage, such as the magnetostriction and acoustic resonance devices, generally produce an intense damage pattern within a span of seconds or minutes. Venturi tubes, variable pressure tunnels, and rotating disc apparatus with suitable fluid stilling vanes produce less intensive cavitation collapse forces at lower frequencies, which result in cavitation damage patterns within a time span of hours to days. Jet impingement equipment<sup>39</sup> and rotating specimens<sup>40</sup> in open water produce damage patterns in terms of weeks to months. Probably in these latter instances cavitation collapse forces may not exist at all or be of very low intensity and frequency.

Inasmuch as the studies of cavitation damage made by the authors were directed toward practical application for ship propellers, it was apparent that an apparatus designed to simulate an operating propeller in open seawater would be most desirable.

#### Boston Cavitation Test Rig

The Bureau of Ships assigned the study of cavitation damage protection by cathodic means to the Boston Naval Shipyard Chemical Laboratory in 1954. An extension of the project includes a study of the deterioration of metals, plastics, coatings and other materials exposed to propeller-type cavitating conditions. The cavitation rig has been designed to take four beveled flat blades (no thrust) which can be electrically isolated from each other or purposely grounded to external electrical circuitry.<sup>41</sup> The blades fit into special sockets machined into the hub, which permits changing the pitch angle as desired. For purposes of the preliminary experiments, cylindrical bars were used instead of blades. The cavitation pattern on various shaped blades, including the cylindrical bars, was determined in the variable pressure water tunnel at David Taylor Model Basin.<sup>42</sup> The basic shape blade and its modification are shown in Figure 3. The two blades and two cylindrical bars were mounted in a hub and rotated at various speeds and pitch angles (for flat blades) in the tunnel at a 10 foot head pressure equal to the actual submergence depth of the full size Boston cavitation rig.

The multiple blade assembly is shown in Figure 4. The cavitation pattern on each of the blades is shown in Figure 5, which are actual photographs taken in the DTMB tunnel by high speed strobe flash techniques. The cavitation patterns observed are drawn schematically in the same figure.

#### Test Apparatus

The test apparatus used in these experiments consists of a rigid steel frame mounted on a side of a barge.<sup>43</sup> Two channels mounted on the frame serve as guide tracks for a carriage that travels up and down. A 2 1/4 inch diameter K-Monel shaft is mounted on the center line of the carriage. The shaft is coupled to a 75 H.P. variable speed d-c motor by means of a flexible coupling. A thrust



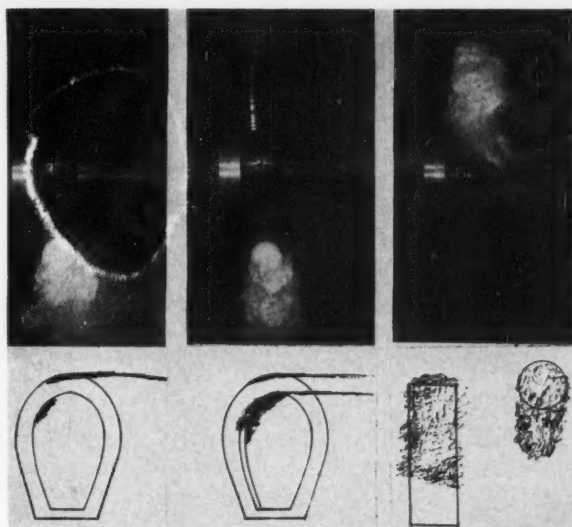


Figure 5—Cavitation on three types of blades. Pitch angle =  $15^{\circ}16'$ ; 1,200 RPM. From DTMB Report 1204, 1958.

bearing is secured to the shaft near the coupling. Two cutless rubber bearings mounted on pillow blocks steady the submerged portion of the shaft. The drive motor is mounted on a shelf secured to the top of the carriage. Up and down movement of the carriage is effected by means of a two-ton electric hoist mounted on top of the stationary frame. The general arrangement of the equipment is shown in Figure 6, and a schematic electrical hook up diagram is shown in Figure 7.

The test propeller hub is keyed to the lower end of the shaft and is secured by means of a tapered lock nut. The propeller assembly is protected from mechanical damage from debris by a cylindrical plastic guard mounted at the lower end of the carriage, as shown in Figure 8. In the event of undue vibration from propeller unbalance or mishap a vibration pick-up device has been installed to shut off power to the motor. The plastic guard is perforated to permit easy circulation of the water and is of a two piece construction. One-half of the guard is secured to the carriage permanently and houses the anode (platinum clad tantalum) used for cathodic protection of the test propeller and the reference electrode (silver-silver chloride)

used for polarization-potential measurements. The other half of the guard is removable to permit access to the test propeller. An expanded metal cover on top of the plastic guard serves to further safeguard the test propeller from debris that might enter from the top of the guard.

The seawater at the test site was checked periodically for pH, temperature, and resistivity. In the summer, the averages were respectively 7.2, 60 F and 30 ohm-cm.

The propeller blade specimens for these tests were cylindrical bars,  $1\frac{1}{2}$  inch diameter x  $6\frac{1}{4}$  inches long, threaded at one end to permit mounting on the hub. Lock nuts prevented the rods from loosening.

#### Test Propeller Assembly

The test propeller assembly consists of a metal cubical hub,  $3\frac{1}{2}$  inches on a side, with a 2 inch tapered bore and a keyway. Each of the four vertical faces is bored and tapped to a depth of  $\frac{3}{4}$  inch x  $1\frac{1}{4}$  inches in diameter to permit removable blades to be screwed into the hub as shown in Figure 8. A metal fairwater serves as an additional lock nut to secure the hub to the shaft and cut down the turbulence caused by the rotating propeller assembly. A set screw on the side of the fairwater prevents it from unscrewing from the shaft.

TABLE 2—Profilometer Readings (RMS) (Manganese Bronze—411 Hours)

Specimens	Micro-inches
New-Unexposed rods.....	90-100
Rods cathodically protected....	90-100
Rods not cathodically protected..	30-300

TABLE 1—Chemical Composition of Specimens

Mild Steel		Manganese Bronze	
Element	Percent by Wt.	Element	Percent by Wt.
Carbon.....	0.24	Copper.....	59.03
Manganese.....	0.46	Zinc.....	38.76
Phosphorous.....	0.016	Tin.....	0.88
Sulfur.....	0.030	Lead.....	0.02
Silicon.....	0.22	Nickel.....	0.00
Nickel.....	0.10	Iron.....	1.10
Copper.....	0.08	Aluminum.....	0.08
Chromium.....	0.07	Manganese.....	0.13
Molybdenum.....	0.09		
Brinell Hardness... 126		Brinell Hardness... 163	

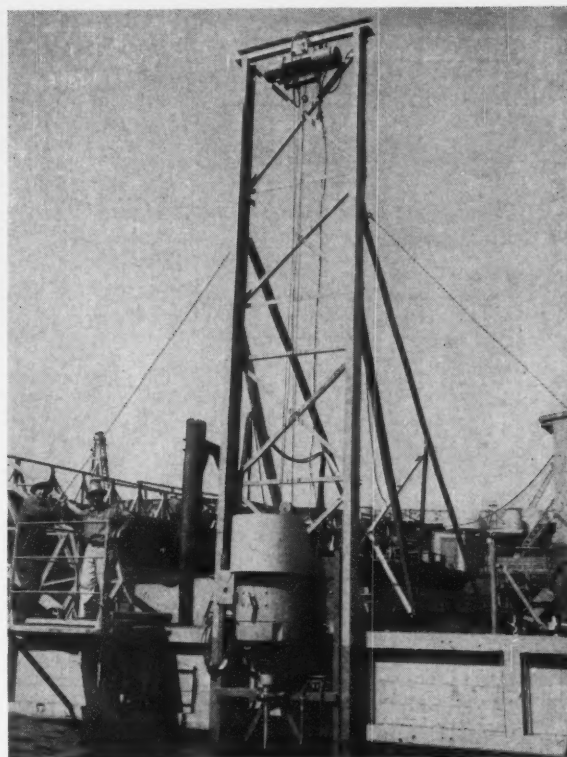


Figure 6—General arrangement of Boston cavitation apparatus.

#### Test Method

Two sets of propeller assemblies were constructed from each of the two metals tested, low alloy steel and manganese bronze. Their compositions are given in Table 1. Each steel and bronze test assembly was rotated at a speed of 1250 rpm in the test apparatus alternately for a period of two days, with one assembly cathodically protected at a specific current density while the other assembly was rotated without the benefit of cathodic protection. Visual inspection of the damage was made at the two day intervals and appropriate photographs were taken.

#### Observations

The initial experiments were made with manganese bronze specimens rotated at 1250 rpm. One series was without cathodic protection and another series with cathodic protection at a current density of 500 ma/sq ft.<sup>43</sup> After 411 hours of exposure, a definite but slight deterioration pattern was observed on the trailing edge of the unprotected rod specimen. The damage was measured by determining the change in surface finish using a brush profilometer and expressing the results in micro-inches (RMS) as shown in Table 2.

Although the intensity of damage in the initial experiments was not impressive, the data obtained were encouraging and further runs were made on mild steel and manganese bronze.

The next series of experiments was run using mild steel cylindrical specimens exposed to various cathodic current densi-



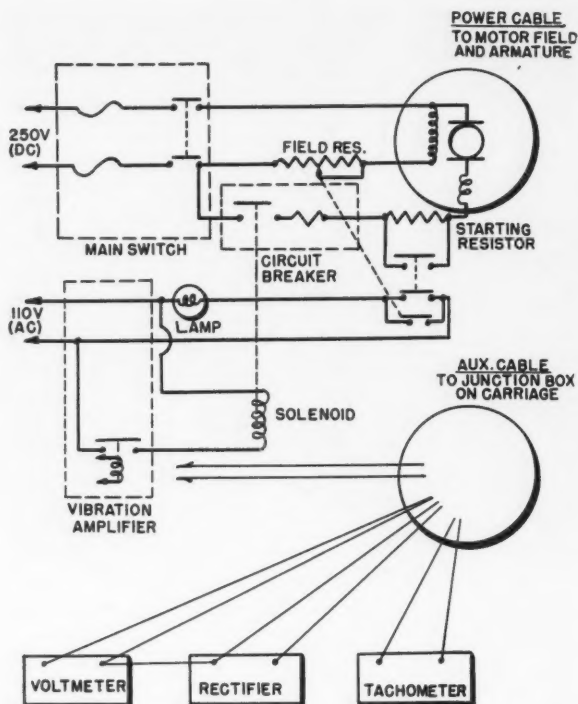


Figure 7—Electrical wiring for control station (BSN Report No. 2380-58).

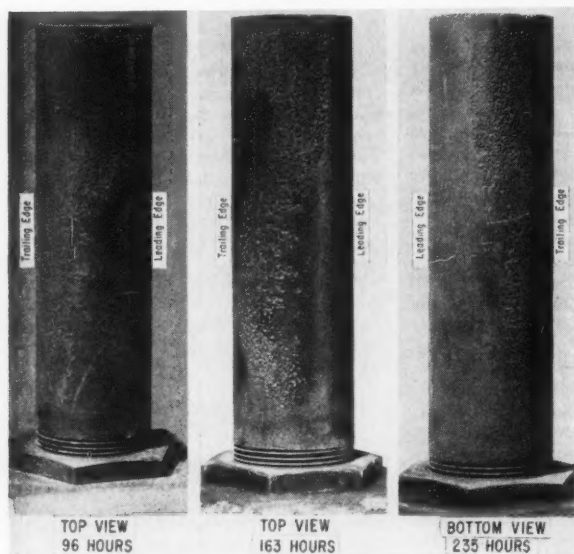


Figure 9—Boston cavitation tests on mild steel specimens; control—no cathodic protection, 1,250 rpm.

ties.<sup>44</sup> The control specimens were exposed for 96, 163, 235 and 527 hours successively without cathodic protection, and the pattern and intensity of damage are shown for a typical rod in Figures 9 and 10. Another series of steel specimens was run for 599 hours protected by a current density of 500 ma/sq ft. Figure 11 shows the complete absence of damage on both leading and trailing edges of a typical specimen.

Another series of steel specimens was

an unprotected control. Figure 12 shows the progressively less damage on the specimens as current density increases, with complete elimination of all damage at the 500 ma/sq ft level. In still another series of experiments, manganese bronze specimens were exposed for 500 hours with and without cathodic protection (500 ma/sq ft). The damage pattern of the unprotected specimens was similar to that of steel but much less intense. The protected specimen again

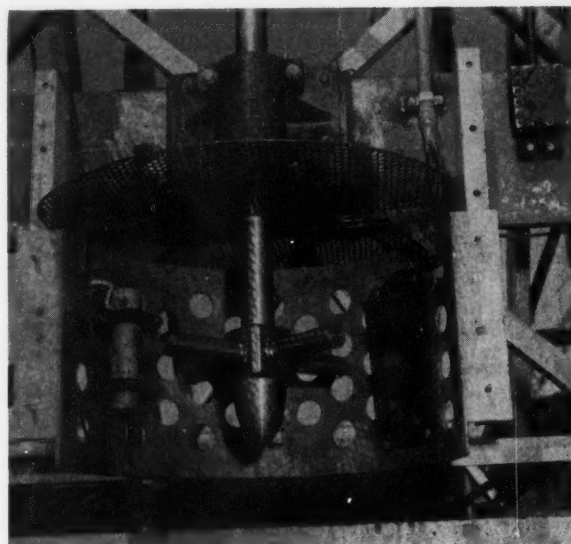


Figure 8—Close-up view of cavitation test propeller assembly.

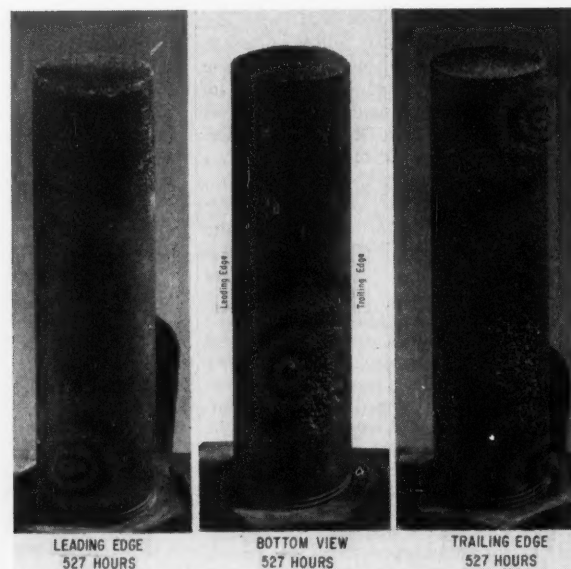


Figure 10—Boston cavitation tests on mild steel specimens; control—no cathodic protection, 1,250 rpm.

exposed for periods up to 215 hours using current densities of 152, 305, 403 and 500 ma/sq ft respectively and compared against

showed no damage on either leading or trailing surface (see Figure 13). Further confirmation of complete cavitation damage protection was obtained on another set of steel specimens exposed for 1100 hours under cathodic conditions (500 ma/sq ft).

### Discussion

In these rather preliminary experiments, it is shown that relatively low levels of cathodic protection current density completely protected rotating specimens from damage under cavitating conditions. Once it can be established, beyond reasonable doubt, that cavitation bubble formation and collapse did actually occur on the specimens during exposure, then it remains to propose a



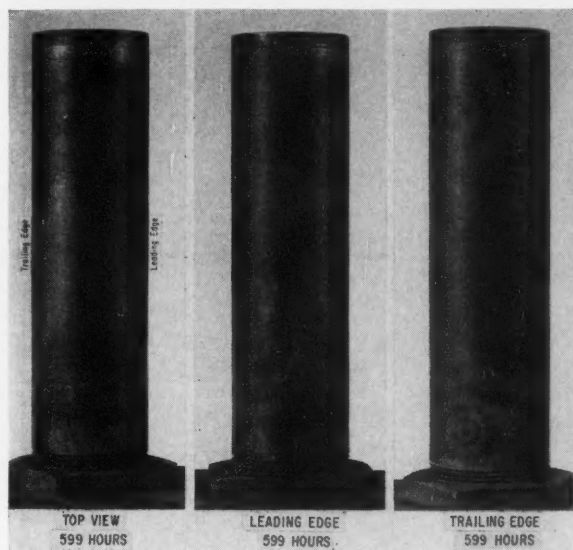


Figure 11—Boston cavitation tests on mild steel specimens (protected at 500 ma/sq ft, 1,250 rpm).

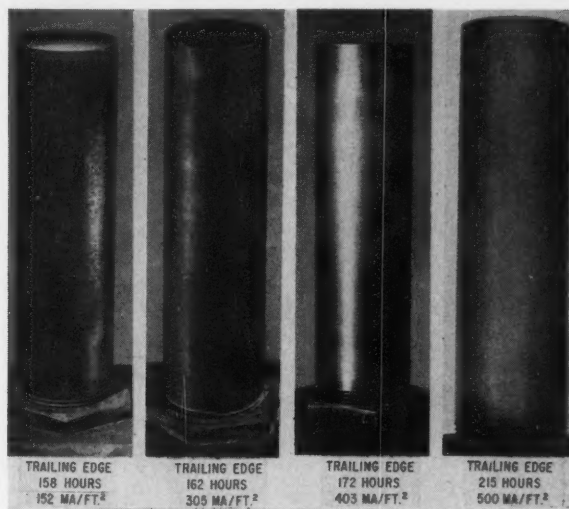


Figure 12—Boston cavitation tests on mild steel specimens showing progressively less damage with increasing cathodic current densities, 1,250 rpm.

mechanism whereby electrochemical phenomena can influence the damage rate caused by the substantial physical forces of cavitation bubble collapse.

#### Cavitating Exposure Conditions

Every attempt was made to design an apparatus which would simulate a cavitating ship propeller in open seawater. The inception and collapse of cavitation bubbles on rotating bar specimens was visually observed under stroboscopic light during full scale calibration tests of the Boston propeller in the variable pressure water tunnel at the David Taylor Model Basin. The observed areas where cavitation collapse occurred in the DTMB tunnel as shown in Figure 5 are similar to the damage pattern obtained on the specimens rotated at 1250 rpm in the Boston Cavitation Test Apparatus.

In addition to the above, underwater sound studies were conducted while the Boston propeller was in operation. A hydrophone underwater sound transducer was located near the propeller. Sound pressure of the operating propeller was converted to a pulsating voltage by the transducer, which was fed into appropriate amplifier, filtering and metering equipment. The intensity of the sound was proportional to the voltage generated and frequency was duplicated by the voltage pulsation. Broad band measurements of sound intensity and analyses at discrete frequencies were made at various propeller speeds with background noise kept to a minimum. At 600 rpm of the propeller, a sharp rise in sound intensity was observed, which increased with increasing speed up to 1250 rpm. The frequency analysis of this sharply defined sound pattern showed it to be characteristic of cavitation bubble collapse when compared to records made by independent investigators at the David Taylor Model Basin.

Another interesting observation which confirms the premise that damage was a result of cavitation phenomena is the

similar pattern of deterioration sustained by both the steel and manganese bronze (although the intensity of attack was less for the bronze).

If the mechanism of damage could be ascribed purely to electrochemical phenomena under velocity conditions, the steel specimens would have corroded from the center outward and the bronze from the center inward. In the case of the steel, differential oxygen concentration would be the influencing corrosion mechanism, while for bronze the influencing corrosion mechanism would be differential ion concentration. Also, if impingement forces were thought to be the cause of the deterioration, the damage pattern would have been concentrated on the leading edge instead of the trailing edge of the propeller rod specimens.

Without laboring the point further, it would seem reasonable to conclude that cavitation forces were responsible for the damage sustained by the propeller blades (rods).

#### Mechanism Of Damage

Since cavitation damage produced in the authors' experiments was completely eliminated by relatively low current densities, a mechanism whereby this phenomena can obtain is postulated.

The total damage to a metal surface can be divided into three distinct groups, each having a specific mechanism:

- (a) Cavitation Deformation or Fracture
- (b) Cavitation Fatigue
- (c) Cavitation Corrosion

It is proposed to do away with the ambiguous term "cavitation erosion" which can apply to mechanisms (a) and (b). In the case of **Cavitation Deformation or Fracture**, all three mechanisms may be superimposed on each other to contribute to the total damage. The second case of **Cavitation Fatigue** may have only the corrosion mechanism operating in concert. The third case of

**Cavitation Corrosion** implies no physical damage to the metal substrate but an electrochemical damage accelerated by cavitation collapse forces. **Cavitation Deformation and Fracture**, resulting from intense hydromechanical forces generated by collapsing cavities under certain conditions, have been demonstrated by Schroeter<sup>45,46</sup> and Hunsaker<sup>47</sup> by deforming lead specimens, by Boetcher<sup>48</sup> who found crystal sliding and twinning in exposed specimens. Recently, Knapp<sup>49</sup> produced pit deformations in soft aluminum using a circulatory cavitation producing apparatus. Schroeter also produced fracture patterns on brittle materials such as glass, agate and quartz by cavitation cavity collapse.

#### Cavitation Deformation and Fracture

Cavitation deformation and fracture is generally experienced on specimens exposed to accelerated tests using magnetostriction or ultrasonic apparatus unless the equipment is adjusted for low frequency, low amplitude operation. Wheeler<sup>4,25</sup> plastically deformed steel in toluene, and Rasmussen<sup>50</sup> fractured plastic materials and cast iron by the magnetostriction method. Plesset and Ellis<sup>51</sup> produced deformation of a zinc monocrystal (X-ray diffraction) by means of an ultrasonic apparatus.

Since in this case the greatest portion of damage is due to mechanical breakdown of the material surface and its subsequent particle separation and ejection from the mass, the secondary fatigue and corrosion effects, although operating, are obscured. Wheeler<sup>4</sup> for instance, showed an increase in total damage when water is substituted for toluene. Shal'nev<sup>38</sup> also demonstrated the increased damage in a magnetostriction device for cast iron specimens exposed to seawater as compared to fresh water. In general, the time scale is so short in which the cavitation deformation and fracture damage occurs that the secondary mechanisms of fatigue and corrosion do not contrib-



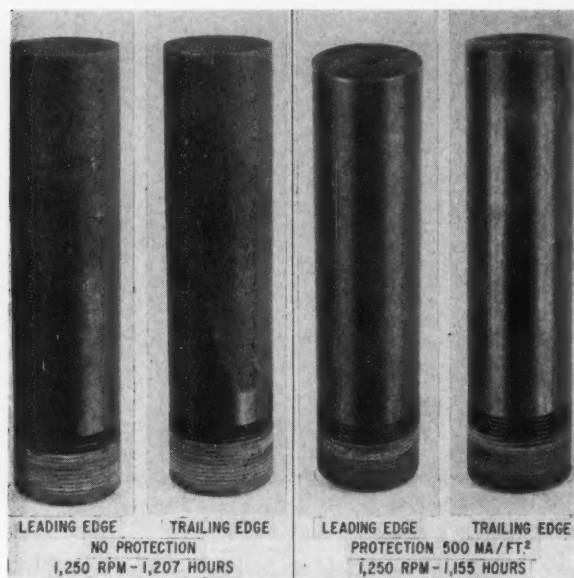


Figure 13—Boston cavitation tests on manganese bronze specimens.

ute substantially to the total damage. The only effective way of reducing this type of damage to the metal surface is by mechanically cushioning the intense implosive forces of cavitation collapse.

The use of entrained air as a mechanical cushion to reduce cavitation damage in concrete hydraulic systems was reported by Veenard<sup>52</sup> and Warnock.<sup>53</sup> Rasmussen<sup>54</sup> also found that entrained air was sufficient to arrest cavitation damage on rotating disc and Venturi type flow devices. The use of hydrogen gas as an overvoltage reaction product of the cathodic process has also been tried with considerable success as a means of introducing a resilient gas cushion between the collapsing vapor cavities and a metal surface.

Leith<sup>9</sup> and Kerr<sup>10</sup> were among the first investigators to suggest that hydrogen cushioning was mainly responsible for eliminating cavitation damage to cast steel specimens in a seawater environment using a standard magnetostriction apparatus designed after Kerr<sup>55</sup> and Rheingans.<sup>56</sup> Current densities in the order of 250 amperes per square foot were claimed to achieve complete protection from cavitation damage in seawater. Attempts to protect cast steel specimens in fresh water were not successful due to the limited current densities which could be applied. However, cathodic protection did increase the incubation time slightly and decrease the weight loss after a 120 minute exposure. Further increases of current density in fresh water failed to increase protection (refer to Figure 14).

Plesset<sup>11</sup> recently reported work, sponsored by Office of Naval Research under the instigation of the authors, on the role of hydrogen cushioning by cathodic generation on cavitation damage. In these experiments, using a magnetostriction apparatus, a dished specimen was chosen after several trials over a flat faced specimen similar to earlier work by Wheeler.<sup>4</sup> The results obtained in the first series

of experiments, Figure 15, showed that current densities of about 50 amperes per square foot reduced the cavitation damage on mild steel by a factor of about 50 percent, 4340 steel by 35 percent, and 17-7PH stainless steel by 60 percent for exposure periods of one hour. Lesser current densities, applied proportionately, increased the cavitation damage for the same period of time. In all cases, from current densities of from  $\frac{1}{2}$  to 50 amperes per square foot, hydrogen gas was evolved at the cathode. Further experiments in buffered distilled water showed a protective effect whether gas was evolved cathodically (hydrogen) or anodically (oxygen). Where no gases were evolved, no protective effect could be shown for anodic or cathodic specimens.

#### Cavitation Fatigue

Cavitation fatigue occurs on metals and other materials when the implosive forces of the collapsing cavities are well below the yield strength of the material. This lower intensity cavitation damage takes place over a longer time scale and therefore allows corrosion mechanisms, when existing, to influence the rate of damage substantially. This type of cavitation damage is believed to be found on most ship propellers and hydraulic machinery and is simulated in the authors' test apparatus. Mr. M. Graham, Head of Materials Laboratory, Boston Naval Shipyard, has shown that typical transgranular fatigue cracks actually occur on propellers in service, which were similar to cracks observed on the manganese bronze test specimens (see Figure 16).

The role of the fatigue mechanism in cavitation damage was recognized over 20 years ago by Boetcher<sup>48</sup> and Mouson.<sup>57</sup> Kerr<sup>10</sup> and Leith<sup>9</sup> observed an in-

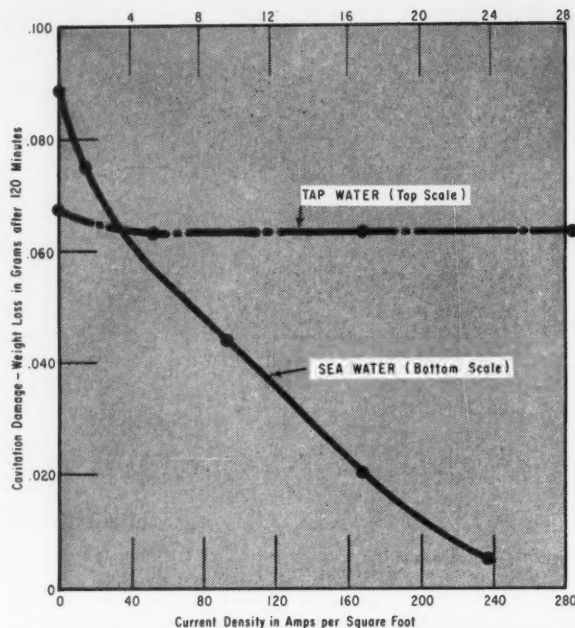


Figure 14—Cathodic protection of cast steel in water. Adopted from W. C. Leith, Dominion Engineering Co. Ltd., Canada (1955).

cubation period before the onset of cavitation damage in their magnetostriction apparatus. This time interval appeared to have a linear relation to the corrosion fatigue properties of the metal under consideration (see Figure 17). For a given material, the incubation time was independent of amplitude, but the weight loss after a fixed period such as two hours appeared dependent on amplitude.

Wheeler<sup>4</sup> was well aware of the interaction between mechanical and corrosion damage in cavitation environments. He postulated the concept that lower severity cavitation collapse forces, greater than surface yield point, initiated slip at grain boundaries. The anodic properties of the grain boundaries when exposed to a corrosive environment would propagate intergranular cracks. Wheeler also reported that cathodic protection in the order of 1 ampere per square foot was effective in eliminating 70 percent of the cavitation damage of mild steel in 0.1N KCl solution at lower cavitation severities.

Wheeler's observations indicate a damage mechanism similar to stress corrosion cracking whereby the severity of cavitation collapse dislocates grain boundaries and causes surface film rupture. The metal under these stressed conditions in a corrosive environment quickly causes anodic solution at the boundaries which progress rapidly because corrosion products are swept from the cracks and polarization effects are removed at the adjacent cathodic grain surfaces.

The experiments of Kerr and Leith substantially support the corrosion fatigue mechanism of transgranular cracking of metal under repeated cyclical stress within the elastic limit in a corrosive environment. It is interesting to note that



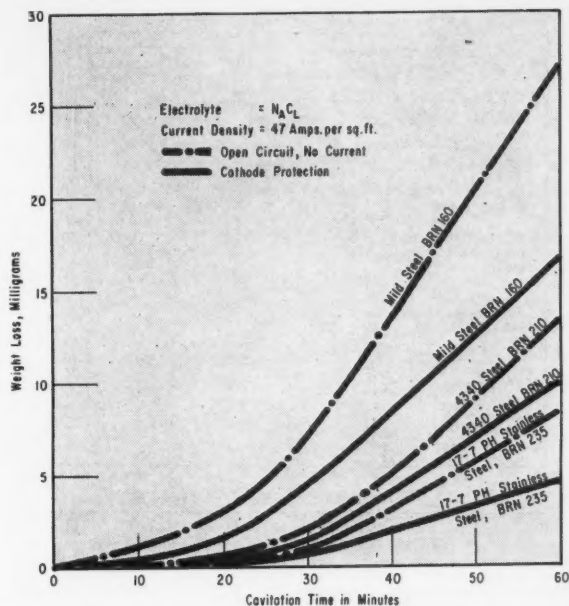


Figure 15—Cavitation damage under cathodic protection conditions (magnetostriction tests). Adopted from M. S. Plesset "on cathodic protection in cavitation damage." ASME paper No. 59A, 170 (1959).

the incubation time did not change with increasing amplitude. It is believed that the constant incubation time, independent of intensity of collapse force (stress), was due to the fact that the corrosion damage to the metal surface was more severe at lower cavitation intensity, while simultaneous mechanical damage was less severe. For high intensity cavitation, the corrosion damage should be less, while the mechanical damage should be higher. Therefore, the sum of the corrosion and mechanical damage tend to remain somewhat constant. Once the protective oxide films are broken down, then corrosion and mechanical forces reinforce each other to produce greater damage with increasing cavitation collapse forces (amplitude).

It is well known that the application of low level cathodic protection (10 to 100 ma/ft<sup>2</sup>) to a specimen undergoing fatigue in a corrosive environment will restore its fatigue limit to that of air.<sup>58</sup> When current densities are applied in excess of those required to arrest corrosion, the consequent hydrogen gas generation partially cushions the fatigue stresses, resulting in longer term resistance to damage.

#### Cavitation Corrosion

When the cavitation collapse forces are of sufficiently low intensity so as not to unduly mechanically stress the metal, the damage is generally confined to the destruction of protective films on the metal surface and the removal of corrosion products. This type of damage, akin to velocity and impingement damage, is designated as the third mechanism, termed **cavitation corrosion**.<sup>27, 36, 39</sup> The damage to a metal occurring in this environment is completely electrochemical and as such can be countered readily by standard cathodic protection techniques. Velocity and turbulence effects promote

corrosion by many accepted mechanisms, namely: protective film breakdown, differential aeration and differential ion concentration.<sup>40</sup> Lichtman et al<sup>30</sup> elaborated on the role of velocity in cavitation damage, which is shown in Figure 18.

Some other theories on electrochemical effects produced by cavitation collapse forces are thermogalvanic potentials by Krenn<sup>8</sup> and others, and the ion disassociation theory by Marboe,<sup>34</sup> Galtung,<sup>35</sup> and others.<sup>59, 60</sup> Whatever the electrochemical mechanism producing cavitation corrosion, it has been demonstrated that velocity corrosion damage can be completely controlled by cathodic protection.<sup>5, 6, 7, 37, 38, 61, 62</sup>

The only point which needs resolution is how can small amounts of hydrogen gas which are evolved at 500 ma/sq ft be effective in cushioning cavitation implosive forces, thereby reducing the fatigue stress implied by the authors. One theory, partially suggested by Eisenberg<sup>63</sup> and amplified further by the authors, is that hydrogen gas evolution, even when formed at discrete points on the metal at relatively low current densities, will form a nucleus for the inception of cavitation vapor bubbles. Rasmussen<sup>64</sup> has shown that small amounts of air well distributed in a cavitation environment will greatly diminish damage to a metal surface. It follows then that the cavitation vapor bubble will combine with the hydrogen gas bubble to form a composite bubble of the two gases. Upon collapse of the composite bubble, the vapor condenses and the compressible, relatively insoluble hydrogen gas component cushions the impact.

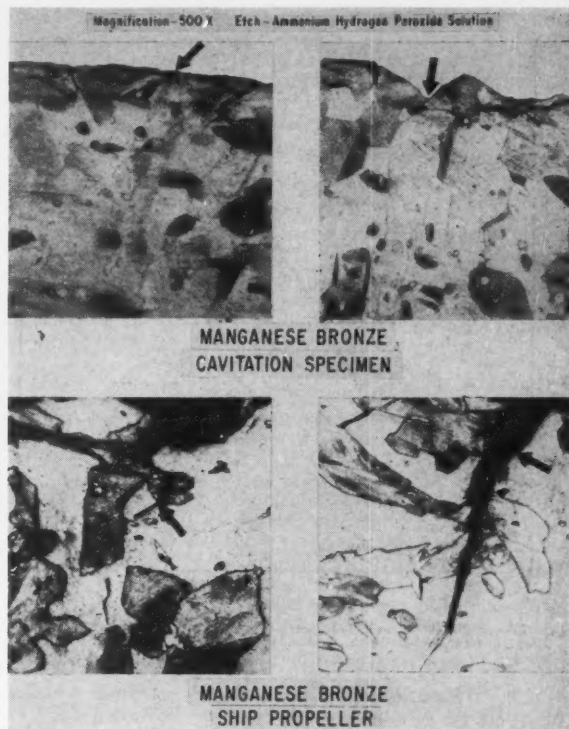


Figure 16—Photomicrographs of specimens and ship propeller showing similar fatigue crack formation during cavitation damage 500X, ammonium hydrogen peroxide etch.

#### Summary

The mechanisms of cavitation damage can generally be divided into three categories relating to collapse force intensities. At severe intensities, cavitation deformation or fracture occurs and the mechanical mechanism of damage predominates, which is not susceptible to ready control by application of cathodic protection. Only by extreme gas cushioning can some reduction to damage be effected. The only remedies in these cases are the use of resistant materials and resilient coatings.

At intermediate cavitation intensities, below the yield point of the material, cavitation fatigue occurs, whereby corrosion fatigue and stress corrosion mechanisms predominate, which are susceptible to control by the application of relatively high current density cathodic protection techniques (under 1 ampere per square foot). In these cases, the limited evolution of hydrogen is effectively used for nucleation of the cavitation vapor bubbles and combining efficiently with them to form an incompressible gas cushion upon collapse. The interference with the mechanical and corrosion components of damage by the means of cathodic protection is an attractive remedy for controlling this type of damage, which is common to marine propellers, pumps, and hydraulic equipment.

At low cavitation intensities, cavitation corrosion occurs, whereby electrochemical corrosion damage predominates. In this case, standard cathodic protection techniques (10-100 ma/sq ft) are completely effective.



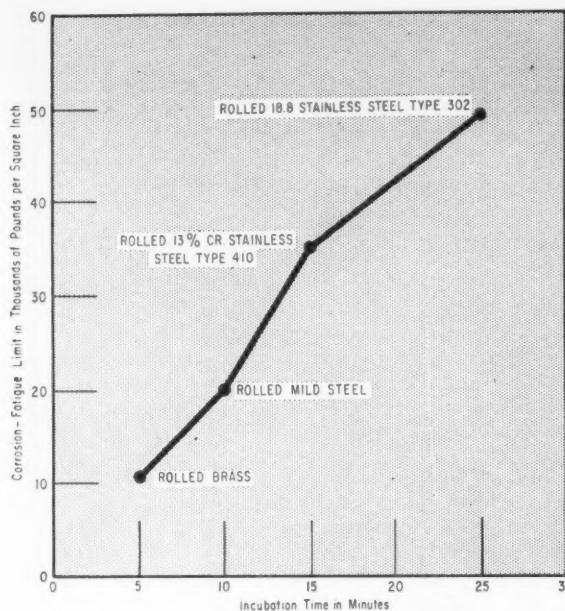


Figure 17—Graph of corrosion fatigue limit of metals and incubation time. Adapted from W. C. Leith, *Dominion Engineering*, 22, 3, 12 (1955).

### Future Studies

Work is in progress at the Boston Naval Shipyard to test brittle plastics and ceramics in the cavitation apparatus to demonstrate cavitation fracture at medium collapse force intensities. An attempt will be made to use non-metallic inserts in the metal propeller specimens to which cathodic protection is applied. This experiment would determine the influence on hydrogen bubble nucleation on the cavitation damage of the insert. Other metals will be tried in a subsequent test series to determine their order of merit in resisting cavitation damage and the effectiveness of cathodic protection in reducing the damage rate.

Plans are also being considered for undertaking a dynamic damage study by means of a cavitation disc probe which substitutes for the standard specimen in the magnetostriction apparatus. This probe, under development by Magna Products, Inc., measures continuously the weight loss of a specimen by well known electrical resistance techniques. The details of typical probes operating on the same principle are described in a paper being concurrently presented at the same NACE Conference.<sup>64</sup>

Other work which should be encouraged is a critical experiment using the magnetostriction device where amplitude and frequency can be adjusted to produce controlled cyclical stresses on a specimen. The stresses produced should be at high intensity, above the yield strength of the material; medium intensity, below the yield strength but in the fatigue range; and light intensity, sufficient to destroy surface films and remove corrosion products. The frequency should be controlled for intermittent operation so that a sufficiently long time scale will permit careful observation of the deterioration of the specimen. Metallics and non-metallics should be compared, as well as similar

specimens in corrosive and non-corrosive environments. Cathodic protection and hydrogen evolution techniques should be applied to selected specimens of a series to determine current densities for maximum effectiveness. The cavitation probe and its associated instrumentation could be used to good advantage in these studies.

One other critical experiment is warranted to test the cavitation bubble nucleation thesis of the authors. A micro-porous sintered specimen should be tested at a suitable amplitude and frequency in a corrosive environment to achieve deterioration by cavitation fatigue. This specimen should be compared with identical specimens under low level cathodic protection (below hydrogen overvoltage) and at high level protection (above hydrogen overvoltage). The final specimen should be protected with low level cathodic protection while simultaneously venting hydrogen gas through the micro-pores from the back of the specimen. The rate of gas passed through this specimen should be equivalent to the Faraday production of gas due to the excess current density of the high level protection on the other specimen. The weight loss of the control specimen without cathodic protection should be the greatest; with low level cathodic protection, less; and the least with high level protection. If the weight loss gas vented specimen corresponds to that of the specimen protected by the higher current density, then it can be concluded with reasonable certainty that small amounts of gas in the vicinity of the cavitation collapse region can critically reduce damage on a metal surface.

### Acknowledgments

The assistance and advice of B. B. Rozene, R. L. Burnett, and M. Graham of the Boston Naval Shipyard; F. E. Cook and R. C. Francis of the Bureau of Ships; and W. L. Miller and S. Tudor of

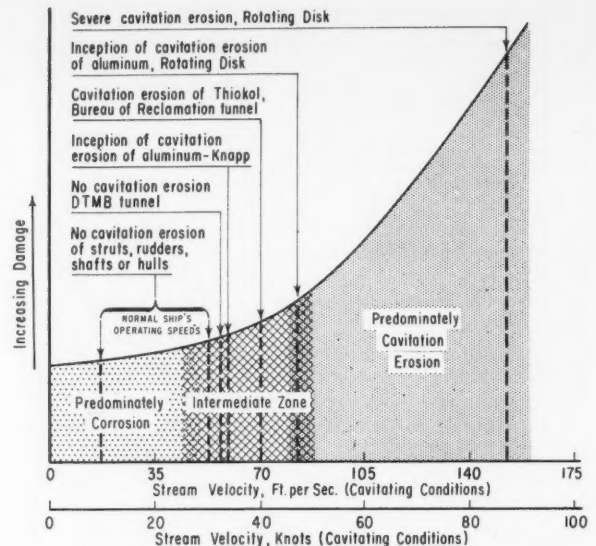


Figure 18—Relationship between fluid velocity and corrosion and cavitation damage of guiding surfaces. Adapted from J. F. Lichtman et al. *Trans ASME*, 80, 6, 1338 (1958) Feb.

the New York Material Laboratory are gratefully acknowledged. Note: The opinions and views expressed in this paper are solely those of the authors and do not necessarily reflect the official views of the Navy Department.

### References

1. D. P. Graham, F. E. Cook and H. S. Preiser. Cathodic Protection in the U.S. Navy, Research-Development-Design. *Trans. Soc. Nav. Archs. & Mar. Engrs.*, 64, 241-317 (1956).
2. G. Petracci. Investigation of Cavitation Corrosion. *Engrs. Dig.*, 10, 9, 314-316 (1949).
3. V. Foltyn. Cathodic Protection Against Cavitation Corrosion. (Translated from *Strojrenstvi, Czechoslovakia*) 2, 9, 402-408, 1952. British Ministry of Supply Translation TIB-4156, 1954 (Jan.).
4. W. H. Wheeler. Mechanism of Cavitation Erosion. Cavitation in Hydromechanics (Proc. National Phys. Lab. Symp., Teddington, England) Paper No. 21, H. M. Stationary Office, London, 1956.
5. R. I. Higgins. Resistance of Cast Iron to Cavitation Erosion. B.C.I.R.A., *Journal of Research and Development (British)*, 7, 28-53, 1957 (Oct.).
6. M. G. Duff. Propeller Corrosion and Cavitation Erosion—Its Prevention by Cathodic Protection. *Corrosion Tech. (British)*, 250-253, 1958 (Aug.).
7. P. Field, L. M. Mosher and A. J. O'Neill. Some Aspects of Propeller Deterioration and Its Prevention. Paper presented to New England Section, Soc. Nav. Archs. & Mar. Engrs., 1956 (May).
8. H. Krenn. Thermo-Electric Corrosion. *Electrical Review*, 543-548, (1949) 23 Sept.
9. W. C. Leith. Mechanical Research at the Dominion Engineering Works, Limited. *Dominion Engineer (Canadian)* 22, 3, 11-15 (1955).
10. S. L. Kerr and W. C. Leith. A Review of Cavitation Damage by the Vibratory Method at the Dominion Engineering Works, Ltd. (Milwaukee Cavitation Committee Meeting), *Amer. Soc. Mech. Engrs.*, (1955) November.
11. M. S. Plesset. On Cathodic Protection in Cavitation Damage. Paper No. 59-A-170, *Amer. Soc. Mech. Engrs.*, 1959.
12. O. Reynolds. Experiments Showing the Boiling of Water in an Open Tube at Ordinary Temperatures. *British Assoc. Adv. Sci., Science Paper* 2, 578-587, 1894.
13. C. A. Parsons and S. S. Cook. Investigation Into the Causes of Corrosion and Erosion of Propellers. *Trans. Inst. of Nav. Arch. (British)*, 61, 223-247 (1919); *Engineering (London)*, 107, 427-428 (1919).
14. F. A. Raven, A. M. Feiler and A. Jespersen. An Annotated Bibliography of Cavitation. David Taylor Model Basin Rep. R-81, 1947 (Dec.).
15. P. Eisenberg. On the Mechanism and Prevention of Cavitation. David Taylor Model Basin Rep. 712, 1950 (July).
16. G. Ziegler. Investigation Into Mechanics of Cavitation. *Engrs. Dig.*, 16, 2, 65-68, (1955) Feb.



17. R. S. Silver. Theory of Stress Due to Collapse of Vapor Bubbles in a Liquid. *Engineering (British)*, 154, 501-502 (1942) 25 Dec.
18. G. W. Sutton. A Photoelastic Study of Strain Waves Caused by Cavitation. *ASME Trans. (J. Applied Mechanics)*, 24, 3, 340-348 (1957) Sept.
19. H. Novotny. The Destruction of Materials by Cavitation. Edward Bros., Inc., Ann Arbor, Michigan, 1946.
20. W. C. Leith. Cavitation Damage of Metals. *The Engineering Journal (Canadian)*, (1959) Mar.
21. W. J. Rheingans. Selecting Materials to Avoid Cavitation Damage. *Materials in Design Engineering*, 102-106, (1958) Sept.
22. R. Beeching. Resistance to Cavitation Erosion. *Trans. Inst. of Engrs. and Shipbuilders in Scotland*, 85, 210-276 (1942).
23. D. Peckner. Causes and Effects of Cavitation. *Corrosion*, 15, No. 5, 269-274, (1959) May.
24. J. Balhan. The Cavitation-Erosion of Ships' Propellers. *Engrs. Dig.*, 14, 5, 163-167 & 170 (1953) May.
25. W. H. Wheeler. Indentation of Metals by Cavitation. *Amer. Soc. Mech. Engrs.*, Paper No. 59-Hyd-15, 82, Series D, No. 1, 184-194 (1960) Mar.
26. T. C. Poulter. The Mechanism of Cavitation Erosion. *J. Appl. Mech.*, A-31-A-37, 1942 (Mar.).
27. D. J. Godfrey. Cavitation Damage—A Review of Present Knowledge (extensive bibliography). *Chem. and Ind. (British)*, 23, 686-691 (1959) 6 June.
28. C. K. Chatten and J. Z. Lichtman. Investigation of Bureau of Reclamation Venturi Type Hydraulic Apparatus for Use in Evaluating the Cavitation Damage Resistance of Elastomeric Coatings. Material Laboratory, N. Y. Naval Shipyard, Project 4759-14, Part 2, Final Report of 2 June 1954.
29. J. Z. Lichtman and C. K. Chatten. Evaluation of a Water Tunnel Apparatus for Use in Determining Serviceability of Elastomeric Coatings for Protection of Metal Members Against Corrosion and Cavitation Erosion Damage. Material Laboratory, N. Y. Naval Shipyard, Project 4759-14, Part 7, Final Report of 4 Oct. 1955.
30. J. Z. Lichtman, D. H. Kallas, C. K. Chatten and E. P. Cochran, Jr. Study of Corrosion and Cavitation Erosion Damage. *Trans. Amer. Soc. Mech. Engrs.*, 80, 6, 1325-1339 (1958) Aug.
31. L. E. Robinson, B. A. Holmes and W. C. Leith. Progress Report on Standardization of the Vibratory Cavitation Test. *Trans. Amer. Soc. Mech. Engrs.*, 80, 1, 103-107 (1958) Jan.
32. A. T. Ellis. Production of Accelerated Damage by an Acoustic Field in a Cylindrical Cavity. *Amer. J. Acoust. Soc.*, 27, 5, 913-921 (1955) Sept.
33. W. Margolis, J. A. McGowan and W. C. Leith. Cavitation Control Through Diesel Engine Water Treatment. *Trans. Soc. Automotive Engrs.*, 65, 331-336 (1957).
34. E. C. Marboe. Gas Evolution from Supersaturated Liquid. *Chem. Eng. News*, 27, 31, 2198-2202 (1949) 1 Aug.
35. E. Galtung. A Study on the Causes of Surface Damages on Ship Propellers. *J. Amer. Soc. Nav. Engrs.*, 65, 389-399 (1953).
36. K. K. Shal'nev. Resistance of Metals to Cavitation Corrosion in Fresh Water and Sea Water (Translated from Dok. Akad. Nauk) (Russian). 95, 2, 229-232 (1954); Canadian Defense Scientific Information Service, DRB Canada, Translation T153R of 29 Nov. 1954.
37. R. I. Higgins. Experiments on the Prevention of Pitting Attack on Cast Iron Propellers by Cathodic Protection. *Corrosion Prev. and Cont. (British)*, 7, Part I, 4, 49-58; Part II, 5, 41-48; Part III, 6, (Corrosion Engineer Supplement) pp. ii-viii (1960).
38. W. C. Leith and L. A. Thompson. Some Corrosion Effects in Accelerated Cavitation Damage. *Amer. Soc. Mech. Engrs.*, Annual Meeting Paper No. 59-A-52, Nov. 29-Dec. 4, 1959.
39. G. T. Callis. A Suggested Mechanism of Cavitation Erosion. *Op. cit.* Cavitation in Hydro-mechanics, Paper No. 18.
40. H. R. Copson. Effects of Velocity on Corrosion by Water (Symp. on Water Corrosion). *Indus. and Eng. Chem.*, 44, 8, 1736-95 (1952) 8 Aug.
41. R. L. Burnette. Preliminary Report on Cavitation Protection Using a Model Propeller. Boston Naval Shipyard Rep. No. 320885 of 2 May 1956.
42. J. G. Peck. Cavitation Areas and Power Requirements for a Cavitation Erosion Propeller. David Taylor Model Basin Rep. No. 1204, 1958 (Jan.).
43. B. H. Tytell, R. L. Burnett and E. Allen. The Boston Naval Shipyard Cavitation Test Unit. Boston Naval Shipyard Rep. No. 2380-58 of 9 June 1958.
44. B. H. Tytell, R. L. Burnett. Cavitation Studies of Metals Using Boston Naval Shipyard Cavitation Test Unit. Boston Naval Shipyard Rep. No. 2490-59 of 20 June 1959.
45. H. Schroeter. Korrosion Durch Kavitation in Einem Diffusor. *L. Ver. Dtsch. Ing. (German)*, 76, 21, 511-512 (1932) May; Eng. Index (British), pp. 677, 1932.
46. H. Schroeter. Erosion Due to Cavitation. *Z. Ver. Dtsch. Ing. (German)*, 77, 32, pp. 365, (1933) Aug; English Abstract, *Mech. Eng.*, 55, 12, 766-767 (1933) Dec.; *Werkstoffzerstörung Durch Kavitation. Z. Ver. Dtsch. Ing.*, 78, 349-351 (1934).
47. J. K. Hunsaker. Cavitation Research—A Progress Report on Work at MIT. *Trans. Amer. Soc. Mech. Engrs.*, 57, 423-424 (1935).
48. H. N. Boetcher. Failure of Metals Due to Cavitation Under Experimental Conditions. *Trans. Amer. Soc. Mech. Engrs.*, 58, 5, 355-360 (1936) 5 July.
49. R. T. Knapp. Recent Investigations of the Mechanics of Cavitation and Cavitation Damage. *Trans. Amer. Soc. Mech. Engrs.*, 77, 7, 1045-54, (1955) Oct.; *Op. cit.* Cavitation in Hydromechanics, Paper No. 19.
50. R. E. H. Rasmussen. Some Experiments on Cavitation Erosion in Water Mixed with Air. *Ibid.*, Paper No. 20.
51. M. S. Plesset and A. T. Ellis. On the Mechanism of Cavitation Damage. *Trans. Amer. Soc. Mech. Engrs.*, 77, 7, 1055-1064 (1955) Oct.
52. J. K. Veenard. Nature of Cavitation (Cavitation in Hyd. Structures Symp. *Proc. Amer. Soc. Civ. Engrs.*, 71, 1000, (1945).
53. J. E. Warnock. Experiences of Bureau of Reclamation. *Ibid.*, pp. 1041.
54. R. E. H. Rasmussen. Experiments on Flow with Cavitation in Water Mixed with Air. *Trans. Danish Academy of Technical Sciences*, No. 1, 3-60, (1949).
55. S. L. Kerr. Determination of the Relative Resistance to Cavitation Erosion by the Vibratory Method. *Trans. Amer. Soc. Mech. Engrs.*, 59, 373-397 (1937).
56. W. J. Rheingans. Accelerated Cavitation Research. *Trans. Amer. Soc. Mech. Engrs.*, 72, 5, 705-719, (1950) July; Resistance of Various Materials to Cavitation Damage. Report of 1956 Cavitation Symposium, *Amer. Soc. Mech. Engrs.*
57. J. M. Mousson. Practical Aspects of Cavitation and Pitting. *Bull. Edison Elec. Inst.*, 5, 9, 373-382, (1937) Sept.; *Ibid.*, 5, 10, 423-430, (1937) Oct.
58. U.S. Naval Engineering Experiment Station. The Effect of High Density Cathodic Currents on the Corrosion Fatigue Characteristics of Propeller Shaft Steel in Sea Water. Letter Report 040133 of 11 Dec. 1957.
59. W. A. Weyl. Some Mechano-Chemical Properties of Water. *ONR (U.S. Navy) Rep. NAVEXOS P-571 of 1 Nov. 1948* (Washington, D. C.).
60. T. P. Hoar. Some Fundamental Features of Mechano-Chemical Attack on Metals. NATO Advisory Group for Aeronautical Research and Development, Report 158 of November, 1957.
61. K. N. Barnard. Prevention of Corrosion of Ships in Seawater. *Research (British)*, 5, Part I, 117-122, (1952) Mar.; *Ibid.*, Part II, 176-180, (1952) Apr.
62. D. S. Tullock. Cathodic Protection of Shipping. *Corrosion Prevention and Control (British)*, 51-52, (1957) June.
63. P. Eisenberg. Modern Developments in the Mechanics of Cavitation, (extensive bibliography). *Applied Mech. Rev.*, 10, 3, 85-89, (1957) Mar.
64. D. Roller, et al. Corrosion Measuring Probes for Ships. Paper presented at annual meeting of National Association of Corrosion Engineers, Buffalo, N.Y., 17-21 March 1961.

## DISCUSSION

### Comments by J. A. H. Carson, Pacific Naval Laboratory, Esquimalt, B. C.:

The authors' logical separation of the effects of cavitation damage into these groups should provide a sound basis for future research and for assessment of the problem. It should also go a long way towards eliminating some of the confusion which seems to exist as to the relative effects of mechanical damage and corrosion.

Their experimental evidence on the benefit of cathodic protection under simulated ship propeller conditions will be most helpful to me in convincing some of the skeptics of the fact that corrosion sometimes plays an important part in cavitation damage.

On Page 112 in their comments on Kerr's and Leith's work, Preiser and Tytell suggest that the constant incubation time before the onset of cavitation damage might be due to a "balancing" out of the rates of mechanical and corrosion damage. I find it difficult to see why

the corrosion rate should decrease with a higher intensity of cavitation. It seems to me more likely that the constant incubation time is due to the time needed for the corrosion to produce a stress raising cavity.

With regard to future work, I wonder if it would not be worthwhile to use cast iron as one of the materials for testing cavitation effects. With cast iron it is particularly easy, by metallographic means, to distinguish between mechanical and corrosion effects. I believe they advocated such examinations at the last Sea Horse Institute meeting, as has Dr. D. J. Godfrey in England.

### Reply by the Authors:

We are delighted that our approach to cavitation damage has been received well by J. A. H. Carson. Referring to his comment regarding the balancing out of corrosion and mechanical damage, the authors have corrected the text to eliminate the word "rates." What was meant was total corrosion decreases with high intensity cavitation since the time scale for damage is considerably shortened. Kindly refer to Mr. Tudor's comments and authors' reply.

Mr. Carson's suggestion of using cast iron specimens to distinguish between corrosion and mechanical damage under metallographical examination is well taken and accepted for the record. It is our understanding that Dr. Godfrey has achieved excellent results with cast iron and the data were to be or have been published recently.

### Comments by Commander E. P. Cochran, Jr., USN:

I have read the paper with great interest. The work reported is a contribution to the understanding of cavitation erosion. Unfortunately the question of the possibility of control of cavitation erosion in a moving stream is not clearly answered. The velocities used—relative velocity of the test specimen to the fluid—are so low as to be in the zone where corrosion is believed to be a major factor in damage. Because of this, the possibility exists that the work reported is an example of cathodic protection of corrosion damage.

I think it is most important that a well designed test be conducted at the earliest available time to determine the degree of control possible of cavitation erosion in sea water under flow conditions.

### Replies by the Authors:

We do not agree that the relative velocity between test specimens and fluid were so low that no cavitation existed. We think the model tests at the David Taylor Basin show sufficient evidence that cavitation collapse was taking place on the blades. However, we do agree that any actual shipboard test of cathodic protection of a cavitating propeller would be most conclusive and desirable. It is our understanding that the navy is considering a special project of this magnitude using a specially designed propeller hub anode.



**Comments by H. H. Collins, Bordesley Hall, Alvechurch, Birmingham, England:**

The paper by Mr. Preiser and Mr. Tytell is of considerable interest to us. The idea that at least two mechanisms, one of corrosion and one of erosion, are present throughout the spectrum of cavitation damage, merely varying in their relative importance, seems very plausible and we have used it for some time as a convenient way of thinking about the problem.

In our experience however the spectrum suggested by Lichtman et al (Figure 18) is not quantitatively representative of the facts, although it is probably qualitatively correct. Certainly we have seen cast iron ship propellers subject to water velocities of up to 110 ft. per second which have been damaged by a process which is essentially corrosion, as indicated partly by the appearance of the damage and partly by the practicability of preventing it by cathodic protection. On the other hand, when cast iron propellers and other components have been subjected to velocities of less than about 50 ft. per second, they are normally found to be free from severe local attack, although of course they may still be subject to general corrosion at rates dictated by the velocity, composition and temperature of the fluid in question.

We are particularly interested in the results from the Boston Cavitation rig and especially those illustrated in Figure 12. These suggest that mild steel moving through seawater at about 120 ft. per second can be cathodically protected by an applied current density of 400-500 milliamperes per sq. ft. It may be noted in passing that this also suggests that the diagram (Figure 18) due to Lichtman et al is inexact quantitatively, since it indicates that a velocity of 120 ft. per second causes predominantly cavitation erosion while the evidence of the cathodic protection suggests that at this velocity the damage is predominantly due to corrosion.

The contrast between the values of 0.5 amperes per sq. ft. and 240 amperes per sq. ft. (Figure 14) required to reduce damage to insignificant proportions in respectively corrosive and erosive conditions is very marked, but in our work on the protection of cast iron propellers we have never found a value of even 0.5 amperes per sq. ft. to be necessary. A current density of 0.03 amperes per sq. ft. is usually sufficient in practice. However there is good evidence to show that the current density required depends on the potential of the propeller. Apparently the important thing is to polarize the propeller to a potential of about -0.85 v. to a copper/saturated copper sulfate half cell. It would be interesting to hear if the authors have noted any similar effect in their work.

**Replies by the Authors:**

We are grateful to H. H. Collins for his discussion. We are in agreement that Lichtman et al (Figure 18) present only a qualitative spectrum and do not take into consideration that the formation of cavities at low velocity flows can still

cause damage in the cavitation fatigue, and cavitation corrosion range.

The comment regarding Figure 12 of the paper should be withdrawn since there was a typographical error appearing in the legend of the copy of the paper he saw. The corrected RPM is 1250 in lieu of 1750 shown in the preprint. Therefore, the velocity under consideration is slightly over 80 fps and not in the 120 fps range.

The data presented by Mr. Collins on the protection of cast iron propellers is valuable. The lower current densities required for full protection are indicative that cavitation corrosion was predominant. Although we agree that current density depends on the potential of the propeller, we have found that above 0.9 volts to the Ag-AgCl cell, additional current only aids in the liberation of more hydrogen and not in increasing potential. We think the most important thing to keep in mind is that the intensity of collapse is not only dependent on velocity of flow, but also on the rate of change of pressures in the fluid stream and the properties of the fluid itself, in particular air content.

**Comments by J. T. Crennell, Central Dockyard Laboratory, H. M. Dockyard, Portsmouth, England:**

I must congratulate the authors on the successful operation of their Boston Test Rig, which has some very important features not paralleled by any laboratory rigs. In particular, in my view, it is much more acceptable than any magnetostriction device, which does not include the high water velocity relative to the specimen. I think this feature is quite vital in any experiments with cathodic protection.

The results which they publish are most interesting, and as they describe them as "rather preliminary," I hope there will be a lot more to follow.

Their sub-division of cavitation damage into distinguishable grades of increasing severity should help to clarify the mechanism. I think many people are beginning to realize that different processes are at work, ranging from corrosion to gross mechanical damage.

I should like to ask them for some additional information which they do not mention, though I think they may well have obtained it. Their description of the test rig includes a reference electrode "for polarization-potential measurements"; but they do not include any such results. I am particularly interested in the current density/potential/water-speed relationships, and if they have any such information it would be most valuable. It has also, of course, a direct bearing on the mechanism of preventing "cavitation corrosion" by cathodic protection. To a first approximation, I should expect the potential required for cathodic protection to be the same at high water speeds as at rest; observation of the minimum "protected potential" in their rig would be very informative.

It is possible that with bronze specimens, (but not I think with rusted steel) the interpretation might be complicated by the fact that some alloys can show a much more anodic potential when their

protective film is removed—e.g. by abrasion, impingement or cavitation—and hence may require a more negative potential for cathodic protection.

**Reply by the Authors:**

The authors thank J. T. Crennell for his support and complimentary comment. Regarding potential measurements made, we found that while the rig was in operation, the closed circuit potentials of the propeller were erratic and meaningless because of interference of the close proximity anode. Open circuit measurements were also inadequate due to the rapid fall of potential while the rig was operating. It was decided to dispense with further measurements until a more suitable technique could be devised. There was an opportunity some time ago to make a potential measurement on an operating ship bronze propeller polarized at 500 ma/sq ft and from memory, we recall a potential to silver-silver chloride of -0.90 volts.

**Comments by M. G. Duff, 1 Guildhall Street, Chichester, Sussex, England:**

I have read the paper with very great interest, more particularly perhaps because it broadly confirms the theories I have myself developed based on practical field work on the problems of propeller breakdown on ships. I would like to offer the authors my congratulations on the admirable presentation of their material, which cannot fail to be of great value to all of us who work in this field.

The description of the test apparatus states that solution potentials of the propeller were recorded with reference to the normal silver/silver chloride half-cell, but does not indicate how connection was made from the voltmeter to the rotating shaft. It would, I think, be of interest to know what means were employed to achieve reliable contact at this point.

I too shall be more happy to see the disappearance of that over-used and misleading phrase "cavitation/erosion." We have here referred for some years to these phenomena under the umbrella name of "cavitation/corrosion/erosion"—listing the causes in what we have believed to be their order of action in the breakdown of a ship propeller: but it is a clumsy phrase and attempts to cover too much. We willingly subscribe to the authors' proposed nomenclature which at least makes a fair attempt to differentiate the preponderant causes in any given case.

As I understand it, the authors hold that cavitation fatigue is the principal cause of damage to ship propellers, and that relatively high (to us) current densities may be required to control damage completely. This is not altogether in line with my experience, and I would suggest that the physical cavitation component plays an almost negligible part in the breakdown of such propellers. Quite low current densities (of the order of 30-50 ma/sq ft) have been found to prevent all damage to uncoated cast iron, manganese bronze and nickel aluminum bronze propellers under service conditions in seawater, even under conditions where the prior breakdown tendency has been severe. We have some hundreds of cases



on record over a period starting about six years ago. Failures have been very few indeed, and I can think of no case where an initial failure has not been overcome by measures other than an increase in current density, or, in one or two current cases, where we cannot foresee overcoming the difficulty without such increase.

To the above I must add that our experience is confined to ships of about 1,000 tons and under, but I believe that by and large the operating conditions of propellers tend to be worse on small vessels than on their larger sisters. On the basis of this experience (and on the assumption that the hydrogen-cushion effect is inconsiderable at such densities) it would seem to me that with ship propellers we are mainly concerned with cavitation corrosion rather than cavitation fatigue.

There is one point of great importance which by the nature of their experiments the authors have not covered, and it would be of great value if they could contribute any helpful information thereon. In practice galvanic anodes are widely used as a source of protective current, and in small vessel work their use is largely unavoidable. This (at the low voltage involved) brings the need for highly efficient shaft-bonding equipment, and in fact most of our difficulties in propeller protection (whether on wood, alloy or steel vessels) are at present associated with this factor.

#### Reply by the Authors:

In reply to M. G. Duff's remarks, we offer the following. The voltmeter connection of the silver-silver chloride cell to the rotating shaft was by means of a silver graphite brush bearing against the upper part of the shaft near the motor, well above the water surface. Even with maximum cavitation, potential readings were erratic and therefore not too meaningful. Refer our reply to Mr. Crennel's comments.

The details of Mr. Duff's experience in operating propellers are a valuable addition to the record. We agree that cavitation corrosion is the probable cause of damage in the cases he cites. Our thesis about propellers, being concerned mainly with cavitation fatigue, applied more particularly to naval ships where speed and loading are nearer design limits than for commercial marine practice.

We concur with Mr. Duff on the need for efficient shaft bonding equipment, especially where cathodic protection is being applied by low voltage galvanic means. U.S. Navy practice has been to use precision fitted bronze slip rings on the section of the shaft aft of the first inboard flange. Electrical contact is then made by conventional brush methods using silver or copper impregnated graphite to reduce wear. We have found this to be an expensive practice and therefore, for commercial vessels, we recommend substituting a metallic foil packing such as lead for part or all of the conventional flux packing in the tailshaft stuffing tube.

#### Comments by F. L. LaQue, The International Nickel Co., Inc., New York, N.Y.:

In addition to the experimental program and results described and discussed in this paper, the authors have provided a very useful discussion of the several forms of damage frequently described loosely as cavitation erosion. I am in agreement with the distinctions they make among cavitation deformation or fracture, cavitation fatigue and cavitation corrosion. However, since more than one of these forms of damage can occur simultaneously, I am not prepared to abandon the use of the term cavitation erosion to describe what may happen. Nevertheless, I see a good deal of merit in using the terms suggested by the authors to indicate which of the aspects of cavitation erosion have been most likely predominant in the damage that is observed.

For many years I have emphasized the defect of many cavitation erosion tests, and particularly those involving high frequency vibrations related to the exaggeration of resistance to mechanical forces relative to resistance to corrosion as a factor in determining the extent of damage that occurs.

For some years Inco has been sponsoring research being undertaken by Dr. M. S. Plesset at the California Institute of Technology having as its objective the development of a cavitation test procedure which would permit more valid comparisons of materials by diminishing the emphasis on mechanical factors and increasing emphasis on corrosion factors. Results of recent experiments which have not yet been published by Dr. Plesset show that by controlled interruption of vibration of test specimens so as to follow a few milliseconds of vibration by a period of rest so that vibration occurs only for about one-twentieth the total time of exposure in the test, it is possible to make clear distinctions between materials having the same hardness with different levels of resistance to corrosion and between corrosive and non-corrosive liquids where materials vulnerable to corrosion are involved. We are confident that further work along this line will result in a method of test that will yield meaningful results and which will permit even more precise evaluation of the influence of applied currents as they may affect the extent of damage by cushioning effects of evolved gases or by electrochemical suppression of corrosion and combination of these two effects.

I am pleased that by work such as reported by the authors of the present paper and by Dr. Plesset we are well along the road to a better understanding of cavitation erosion and how to control such damage either by choice of material, application of protective currents, or combinations of such steps.

#### Reply by the Authors:

We are pleased with the kind comment by F. L. LaQue and are happy to learn of the controlled interruption or time delayed bursts of cavitation studies being conducted by Dr. M. S. Plesset. The authors have advocated this approach for

the past several years and are certain that it will yield comprehensive and fruitful results.

#### Comments by W. C. Leith, Dominion Engineering Works Limited, Montreal, Canada:

This paper is a timely contribution on the electrochemical approach to cavitation damage, specifically for a cavitating ship's propeller in open seawater. The authors are to be congratulated for this excellent review and summary. However, the distinct advantages of cathodic protection in seawater are hardly directly applicable to the general field of cavitation, including closed liquid systems using distilled water, aircraft hydraulic fluid, lubricating oils, and liquid metals.

The writer disagrees with the statement that "inhibitive additions generally do not alter cavitation damage when studied under accelerated laboratory conditions," since we have studied the role of contaminants in closed liquid systems with some success. The following data were observed first in the standard ASME magnetostriiction test and later confirmed by field experience:

(a) 0.01 percent copper ions added to distilled water at 76 F increases the intensity of cavitation attack on aluminum by 40 percent.

(b) 0.03 percent anti-foam agent added to diesel lubricating oil at 200 F increases the intensity of cavitation attack on aluminum by 300 percent.

(c) 0.2 percent buffered chromate or organic inhibitor added to distilled water at 170 F decreases the intensity of cavitation attack on cast iron by 60 percent.

The authors have mentioned the structural variations in materials, but the importance of these effects is not generally discussed. A few examples may be of interest:

(a) The commercial tolerances on the porosity and non-homogeneity of alloy cast iron used in diesel cylinder liners often spells the difference between slight and serious cavitation damage.

(b) The slightly higher density or specific gravity of weld metal joining rolled metal of the identical chemical composition can be neglected in water turbines, but the decreases of corrosion resistance of the parent metal at the weld boundary could be important for hydrofoil craft operating in seawater.

Perhaps the early work of Ramsay (1912)\* could have been referred to, since he was one of the first to suggest an electrochemical concept of cavitation damage.

#### Reply by the Authors:

The comments by Dr. W. C. Leith are accepted with appreciation as a valuable addition to our paper. We are glad to see data which show that the effect of inhibitive additions on cavitation damage can be detected under accelerated laboratory conditions.

The examples given of the effects of structural variations in materials on cavi-

\* W. Ramsay, Corrosion of Bronze Propellers, Engineering, London, Vol. 93, pp. 687-690



tation damage are gratefully acknowledged, as is the early reference to W. Ramsay.

**Comments by J. Z. Lichtman, Naval Material Laboratory, New York Naval Shipyard, Brooklyn, N.Y.:**

The authors' paper is a valuable contribution to the development of methods of control of cavitation erosion under conditions more closely simulating service conditions than many reported to date. This discussion will relate to several areas, as follows:

- a. Terminology
- b. Experimental conditions
- c. Further studies

**a. Terminology.**

The introduction of new terminology is not believed justified if definitions of presently used terms are agreed on.

The presently accepted<sup>1</sup> term "cavitation erosion" is defined as material damage caused primarily by mechanical stress impingement associated with cavitation bubble collapse. The stress level may exceed the yield strength of the material or may exceed the fatigue strength resulting in fatigue erosion. Also the terms "corrosion" or "erosion corrosion" used by previous investigators<sup>2,3</sup> are defined as electrochemical damage of metals, influenced by environmental factors including fluid velocities and scouring removal of protective films. It is believed that the use of more restrictive terminology proposed by the authors in lieu of the above terms may tend to confuse rather than clarify the understanding of the basic mechanisms involved.

**b. Experimental Conditions.**

The rotating bar experiments described by the authors were reported as having been carried out under conditions such that cavitation erosion due to stress fatigue of the metallic bars was obtained. Polarization of the bars was then believed to result in hydrogen evaluation and cushioning of the collapsing cavitation bubbles, thus diminishing the erosion. However, the discussor believes, for the following reasons, that the observed damage was primarily caused by corrosion (as defined above) and the decrease of damage under polarization was due to decrease of corrosion by cathodic protection, and not due to control of cavitation erosion.

**1. Distribution of Damage Along Bars.**

It is noted that the bars, Figures 9 and 10, showed damage extending from the ends to within approximately 1 inch of the hub. High degrees of damage were indicated at the ends and toward the hub and a lower degree seemed to occur between these two areas. The occurrence of damage closer to the hub resembles the condition observed by LaQue when 5 inch diameter cast iron disks were rotated at 1140 rpm, as described by Copson.<sup>3</sup>

**2. Velocity of Specimen Rotation.**

At a shaft speed of 1250 rpm, the linear tip velocity of the bars is calculated to be approximately 80 fps. Knapp<sup>4</sup> and the

discusser and co-authors<sup>5</sup> have found that the impingement intensity of cavitation bubble collapse increases approximately as the 6th power of fluid velocity, using ogival bodies mounted in a water tunnel and a rotating disk having radially located cavitation sources. Also it was found that below velocities of approximately 60 fps, the impingement intensity was too low to cause yield or fatigue of very low yield strength materials such as aluminum 1100-0. Similar observations were made by Rasmussen<sup>6,7</sup> and Shal'nev,<sup>8</sup> using bar specimens in water tunnels. In view of the lower linear velocity of the bars except at the ends, it is unlikely that the observed damage was cavitation erosion caused by impingement fatigue.

**c. Future Studies.**

The questions raised regarding the experimental conditions used by the authors may be resolved by carrying out similar experiments in fresh water so that corrosion factors would be absent. If cavitation erosion of the bars was occurring in sea water, comparable erosion would also occur in fresh water. As an alternate to these experiments, the discussor suggested in August 1959 in comment on a report by Rozen and co-authors<sup>9</sup> that experiments be carried out in sea water using non-metallic specimens (low impact resistant styrene, polyester or PVC bars). Plastic coatings of these or epoxy types also may be applied directly to the metallic bars. These plastic materials have been found<sup>6</sup> to have lower cavitation erosion resistance than the metals used by the authors and therefore would erode more rapidly in a cavitation erosion environment. However, if the cavitation collapse stresses are actually of a level too low to cause erosion or if collapse occurs downstream from the bars, the plastic bars or coatings would show no damage. Regarding the matter of current densities used by the authors it should be noted that these values are considerably lower than those used by Plesset<sup>10</sup> and Leith.<sup>11</sup> Further study of these differences should be made to determine the degree to which hydrogen evaluation is being obtained in the Boston experiments and its relation to the work of Plesset and Leith.

**References**

1. H. H. Uhlig, *The Corrosion Handbook*, New York, John Wiley & Sons, Inc. 1948, p. 597.
2. U. R. Evans, *Metallic Corrosion, Passivity and Protection*, Edward Arnold and Company, London, 1948.
3. H. R. Copson, *Effects of Velocity on Corrosion by Water*, *Ind. and Eng. Chem.* 44, 1745 August (1952) Aug.
4. R. T. Knapp, *Recent Investigations of the Mechanics of Cavitation and Cavitation Damage*, *Trans. ASME*, 77, 1045-1054 (1955).
5. J. Z. Lichtman, D. H. Kallas, C. K. Chatten and E. P. Cochran, Jr., *Trans. ASME*, 80, No. 6, 1325-1341, (1958) Aug.
6. R. E. H. Rasmussen, *Experiments on Flow with Cavitation in Water Mixed with Air*, *Trans. Dan Acad Technical Science*, ATS 1949, No. 1.
7. R. E. H. Rasmussen, *Some Experiments on Cavitation Erosion in Water Mixed with Air*, National Physical Lab. Symposium—Cavitation in Hydrodynamics, Paper 20, London, Her Majesty's Stationery Office, 1956.
8. K. K. Shal'nev, *Experimental Study of the Intensity of Erosion due to Cavitation*, National Physical Lab. Symposium—Cavitation in Hydrodynamics, Paper 22, London, Her Majesty's Stationery Office, 1956.

9. B. B. Rosene, B. H. Tytell and R. L. Burnett, *Cavitation Studies of Metals Using Boston Naval Shipyard Cavitation Test Unit*, Boston Naval Shipyard (Chemical Laboratory) Report No. 2490-59, 20 June 1959.
10. M. S. Plesset, *On Cathodic Protection in Cavitation Damage* (59A170), *Trans. ASME, Jour. of Basic Engineering*, 82, Ser. D, No. 4, 808-820 (1960) Dec.
11. W. C. Leith and A. L. Thompson, *Some Corrosion Effects in Accelerated Cavitation Damage*, (59A-52), *Trans. ASME, Jour. of Basic Engineering*, 82, Ser. D, No. 4, 795-807 (1960) Dec.

**Reply by the Authors:**

We wish to thank Mr. J. Z. Lichtman for his comprehensive discussion of our paper. We are sorry to learn that our separation of the various types of cavitation damage does not meet with Mr. Lichtman's approval. However, we feel confident that there is a growing body of thought in this country and abroad that supports our view.

We take exception to Mr. Lichtman's contention that the damage observed on the bars was distributed in the manner he describes. The damage was decreasingly less from the tips of the bars down the length. In fact, since the patterns, except for intensity, were identical for both the steel and bronze specimens, we reiterate that the simple corrosion mechanism under velocity conditions did not occur. We object to the idea that velocity of the specimen is the only parameter that is valid in determining the intensity of cavitation. Here again, the rate of formation and collapse and the repetitive concentration of the collapsing cavities are significant factors to cause fatigue. The transgranular cracking observed on damaged areas of the specimen was similar to that observed on an actual propeller (Figure 16) and therefore, further substantiates the conclusion that cavitation fatigue was present.

Regarding future studies, it is true that low impact plastics should show evidence of mechanical damage when subjected to similar test conditions. We agree that fresh water tests would be useful in that fatigue damage should still be present even though corrosion factors are reduced. The damage would be expected to be produced over a longer exposure interval.

Regarding current densities, no attempt was made to reproduce the current densities used by Leith or Plesset since they were operating in the cavitation deformation range and therefore needed full mechanical cushioning to reduce collapse forces on the metal surface. Our experiment was to show that with relatively small amounts of current, we were able to protect the specimen from corrosion and generate enough hydrogen to cause nucleation of the cavitation bubbles to reduce their impact upon implosion. There has been no attempt or purpose to relate these current values to those of Leith or Plesset because of the fundamental difference in the prevalent damaging mechanism.

**Comments by J. H. Morgan, 11 Imber Grove, Esher, Surrey, England:**

Among the theories of cavitation damage are several which propose that the



damage is the result of ionization phenomena.

One of the most acceptable ways of looking at this theory is to assume that there is some form of charge separation taking place within the ionized cavity, and giving to this separation some random quality. This may merely be a random variation upon a definite trend of separation in one direction, or, alternatively, it may be the result of completely random separation giving reversal of polarity with respect to the cavitating surface.

Some of the attractive points of this hypothesis are that it explains the reason for damage at the point of cavity collapse, and not at the point of cavity initiation, and also, to some extent, accounts for the severity of the attack, and for such phenomena as the bluing of steel under high intensity cavitation. It would also account for the partial success at present achieved with many applications of cathodic protection.

It might be reasonable to reassess the criterion for cathodic protection in the light of this hypothesis. If the mechanism of cavitation damage is to create a small dipole which discharges itself and when this occurs so as to involve a metal, then that metal is electrolytically dissolved, we have somewhat different conditions from those normally suggested in galvanic corrosion. If we take the simplest case, we are creating a small dipole, which extends from the metal surface some distance into the electrolyte; to prevent its formation we must create a potential gradient, which stops charge separation or, if charge separation occurs, which balances out the dipole on its formation.

The criterion for protection now would seem to be that we create a potential gradient in the electrolyte, close to the surface. It may not be possible to use the effect of polarization at the immediate interface in calculating this potential gradient.

If this is the case then it will be much easier to protect against cavitation damage in fresh water than in sea water. There have been cases of this reported, though they are not sufficient to offer as evidence.

If the charge separation occurs as a random process then at a particular level of cathodic protection some cavities will not produce a destructive dipole, whereas others will, and thus a small amount of corrosion or cavitation attack will occur. Many cases are reported where what appears to be adequate cathodic protection under static conditions was not adequate in the presence of cavitation, though a considerable amount of corrosion was suppressed. It may be that a new criterion of protection is necessary. It certainly would seem that some cathodic reaction on the surface does some good, while to achieve complete protection a considerable potential gradient may be necessary.

Absolute protection may not be as easily realized, because of the occasional large dipole, as it is in the case of conventional corrosion and cathodic protection.

#### Reply by the Authors:

The theory proposed by J. H. Morgan is quite interesting and plausible provided that one accepts the idea that all cavitation damage is electrochemical in origin. The theory fails to take into consideration fracture failures caused by the mechanical severity of cavity collapse under certain flow conditions. The advantage of the authors' hypothesis is that it does not abrogate the mechanical view of cavitation damage but merely extends the spectrum of cavitation intensity to include damage by predominately other mechanisms such as fatigue and corrosion.

#### Comments by L. M. Mosher, Bethlehem Steel Co., Quincy, Mass.:

The authors have presented an interesting concept of the mechanisms responsible for cavitation damage. Their subdivision of these mechanisms into three groupings in terms of severity appears to be a reasonable approach to the problem. It would appear to the writer that some clarification of the authors' grouping of "cavitation corrosion" is in order. There is no doubt that metal damage can occur as a result of the destruction of its protective films and/or the removal of corrosion products that might exert a stifling effect. It is significant that this damage may be strongly accelerated by anodic-cathodic considerations if the above destruction of protective films or corrosion products is a localized effect. As stated by the authors, cavitation collapse forces can cause such damage. However, the same end results can be produced by the scouring effect of moving liquids whether or not they contain abrasives or other contaminants. It follows that velocity and other erosive forces can accelerate corrosion damage in the absence of cavitation effects. "Erosion-corrosion" still appears to be the most descriptive term for the latter type of damage. This suggests that the authors' term "cavitation corrosion" should be used only when film damage is known to be attributable to cavitation forces.

#### Reply by the Authors:

We thank L. M. Mosher for his thoughtful remarks. It is true that any method of mechanically removing protective films and corrosion products from a metal will cause an acceleration of the corrosion process, especially where such action is localized. We agree that under certain conditions, moving liquids may exert enough of an erosive force to cause disruption of these films without the presence of cavitation. There is no objection to the term "erosion-corrosion" as long as it can be confined to describing the above type of damage. We would like to see a Corrosion Glossary, such as in the *Corrosion Handbook*, revised so as to include more rigorous definitions of these phenomena.

#### Comments by Wm. J. Rheingans, Allis-Chalmers Manufacturing Company, York, Pa.:

There has been much speculation in recent years as to the effects of cathodic

protection against cavitation damage. Numerous experimental tests have been made using accelerated cavitation apparatus with varying results.

The author used a new technique in reproducing very nearly the prototype conditions with his test rig. In general, cathodic protection tests using accelerated cavitation apparatus differ from prototype conditions in two important respects: The severity of the implosive forces of the collapsing cavities and the absence of relative high velocity flow between the test specimen and the test liquid. Accelerated cavitation apparatus produces rapid removal of material indicating cavitation deformation and fracture. The time required to produce serious damage on the test specimen is so short that the effect of cavitation fatigue or cavitation corrosion is negligible.

The absence of flow in the accelerated tests tends to permit the accumulation on the test specimen of gas bubbles released by cathodic action. Where the liquid flows over the test specimen, continual removal of the gas bubbles at various rates presents an entirely different problem, as was pointed out by Plesset.<sup>11</sup>

The test rig used by the author produces cavitation conditions and damage very similar to that of the prototype and during about the same time interval. Thus, the full effect of cavitation fatigue and corrosion is present during the tests.

However, the flow pattern of the prototype is not reproduced by rotating the test specimens in still water. Furthermore, the flow over blades would have been closer to the prototype flow than the flow over the cylindrical rods used for the preliminary test.

It is quite possible that the flow pattern has very little effect on cathodic protection. The best way to determine this would be to try it on a prototype under actual service conditions.

The author presents an interesting discussion on the various types of cavitation damage, and his analysis is supported by our present extensive knowledge of cavitation phenomena. However, he may find it difficult to obtain general acceptance of the three terms suggested when reference is made to overall cavitation damage. Admittedly "cavitation erosion" is more or less ambiguous. Therefore, we may have to settle on "cavitation damage" as being somewhat more descriptive of the three types of damage outlined.

The author has proposed a comprehensive and interesting program for future studies which should go a long way in adding to our knowledge of cavitation. In the interests of hydraulic machinery which operates in fresh water, similar studies using the author's technique in fresh water would be of considerable value. The most interesting test, of course, would be to try the cathodic protection on prototype ship propellers.

#### Reply by the Authors:

W. J. Rheingans' analysis is very informative. It is true that flow over blades would have been closer to the prototype than flow over rods, but here again we



were faced with the problem of designing a no-thrust blade or increasing the power to drive the model propeller and providing suitable holding arrangements for the barge. There is no doubt that cathodic protection of actual ship propeller operating under cavitating conditions should yield more conclusive information. The authors are planning further work along these lines.

**Comments by T. Howard Rogers, Defence Research Board, Naval Research Establishment, Dockyard Laboratory, HMC Dockyard, Halifax, N. S.:**

I was very attracted by the paper because it puts on paper, I think for the first time, ideas that I and my colleagues have had on this subject. Our opinions, however, have been engendered more by the assessment of practical failures than by laboratory experiment. I cannot say we have examined hundreds of cases of cavitation damage, but we have examined dozens, and not on propellers alone. We have thought for some time that:

(a) The magnetostriction apparatus, though a useful tool in cavitation damage research, does not reproduce the type of attack or conditions usually found in service failures.

(b) There is more than one type of cavitation damage, or shall we say there is more than one level of cavitation damage and they are fairly distinct. We could perhaps argue the limits of your classifications, but they are a good approximation.

(c) In our opinion the success of cathodic protection as a preventive measure will depend upon the type and level of cavitation present. May we say we do not consider damping by bubbles to be cathodic protection, nor can this type of protection be used to indicate quantitatively the amount of the electrochemical component in cavitation damage. We wonder if you have seen the three papers by Higgins on the Cathodic Protection of Cast Iron Propellers published earlier this year in *Corrosion Prevention and Control*.

Two final points. We are becoming more and more convinced that impingement attack and cavitation damage are not the same thing, and we are beginning to wonder if perhaps the repair of cavitation damage areas on propellers is not more lasting, if a softish fill like a tin-base solder is used in lieu of hard welding. We may be able to use plastic patching.

#### Reply by the Authors:

T. H. Rogers' comments are greatly appreciated. We concur with the idea that cathodic protection as a preventive measure will depend on the level or intensity of cavitation present. The damping of cavitation bubbles by the formation of cathodic hydrogen bubbles is a step beyond simple cathodic protection and as such, any reduction in cavitation damage is due both to the lessening of mechanical forces and the elimination of corrosion forces. Therefore, quantitative separation of the electrochemical com-

ponent of cavitation damage can only be realized by careful experimentation in which the mechanical aspects of the damage are not altered by any suppression of the electrochemical forces. This would require an exact balancing of corrosion current by cathodic protection current.

The articles by R. I. Higgins referred to by Mr. Rogers were read by the authors and are included in Reference 37 of the manuscript.

Regarding the last comment by Mr. Rogers, more work will be required to distinguish cavitation corrosion damage from impingement attack. We believe that impingement attack is of a lower order of mechanical intensity than cavitation collapse, both of which accelerate corrosion reactions. The idea of using soft patches for repair of areas of propellers damaged by cavitation has merit, especially if the fill material is corrosion resistant and has mechanical resilience and toughness. Some work along these lines was done by the U.S. Navy, but no follow-up on the results has been made available.

**Comments by S. Tudor, Naval Material Laboratory, New York Naval Shipyard, Brooklyn 1, N.Y.:**

The authors are to be congratulated for an interesting analysis of the cavitation damage mechanism theory and for providing a clarification of the forces reacting to cause such damage. The definition of several types of damage mechanisms which may act simultaneously and synergistically appears quite reasonable. Considerably more work will be required in the field to pin down the all important degrees of influence of each of the mechanisms for specific applications. Results of the future work listed in the paper should be of continued interest.

The three proposed mechanisms include cavitation deformation, cavitation fatigue and cavitation corrosion. Actually, the influence of electrochemical corrosion, apart from cavitation, should also be considered as a cause of damage. There is no reason to believe that the mechanism of damage ascribed purely to electrochemical phenomena under velocity conditions, such as spinning discs used by Ffield, O'Neil and Mosher with steel specimens corroding from the center outward and bronze from the center inward, would not be occurring simultaneously with the cavitation procedures listed. Damage due to electrochemical corrosion should be considered along with the three proposed cavitation categories. The relative degree of influence of each mechanism is the important criterion.

In connection with ship propeller damage, cavitation fatigue is reported to be found on most ship propellers. I should like to ask whether the damage shown in Figure 2 is considered to be of this type. Also, on what part of the propeller blade did this damage occur?

Several differences are noted between the damage to the cylindrical rod specimens and the propeller shown in Figure 2.

a. Damage in Figure 2 and similar damage I have observed on other Navy ship propellers was very localized, with isolated regions of severe damage rather than zones of relatively similar depths of pits as shown in the trailing portions of the cylindrical specimens. I had the privilege of viewing early damage to several of the cylindrical specimens and commented then that initial damage zones generally conformed to the velocity patterns attributed to electrochemical phenomena. The authors did not concur in this opinion.

b. Current densities of up to 0.5 amp/sq ft were required to prevent damage. This is the same range used by Ffield, O'Neil and Mosher in their spinning disc experiments to prevent damage attributed purely to electrochemical phenomena.

I should like to ask the authors' opinion of the reason for the behavior in sea and tap water described in Figure 14. Is the strong influence of electrochemical corrosion and its relative absence in tap water a possible explanation?

On Pages 112 and 113, how do the authors justify a lower corrosion damage rate under higher intensity cavitation conditions?

Definition of cavitation damage mechanisms on the basis of severity of conditions and resultant types of damage is a fine contribution. The hazards of extrapolating results of severe, accelerated test conditions to describe long term service damage are well pointed out in the paper.

#### Reply by the Authors:

S. Tudor's constructive remarks cover several aspects of the paper and are answered as follows: We believe that the category "cavitation corrosion" covers damage caused by electrochemical corrosion and it is redundant to subdivide this category any further. We are not concerned with electrochemical corrosion of metals under velocity conditions *per se*, but only with accelerated electrochemical corrosion caused by mild cavity collapse below the fatigue intensity on metal surfaces. This type of cavitation is destructive only to surface films and encourages dynamic corrosion mechanisms to intensify their action. However, when film-forming mechanisms control electrolytic behavior of a metal such as bronze under velocity conditions, then the pattern of corrosion under cavitation conditions can differ markedly from the pattern produced under simple velocity conditions.

We consider the damage shown in Figure 2 to be due to cavitation fatigue. This typical pattern occurred near the hub at about the 0.3 radius, an area of severe cross flows and maximum bending movement which is believed to be the cause of isolated, localized damage patterns observed on ship propellers.

The current densities used by Ffield et al for protection of bronze at 100 fps was 75 ma/sq ft and for steel, 1950 ma/sq ft. These current densities are a function of oxygen diffusion rate to the specimens. In the case of steel, corrosion was accelerated since oxygen acted as a



powerful depolarizer, while for the bronze, oxygen aided in maintaining protective films. These current densities are only representative of a specific situation and cannot be used as absolute values. The current densities used by the authors under "cavitating fatigue" conditions are also a function of specific conditions, although the attempt was made to simulate an actual ship propeller environment. We believe that the true criterion for protection will be related to polarization potentials and hydrogen overvoltage values.

Regarding Figure 14, the current density scale for tap water which appeared in the preprint you saw should have been shown as 1/10 the value as for seawater. The graph now appearing in the text is the corrected one. The failure to reduce damage in tap water by increasing current density is due to the high resistance of the water which did not permit sufficient current to flow to have any large effect. In this case of intensive cavitation, hydrogen cushioning was primarily responsible for damage reduction, which was not obtainable in fresh water.

On Page 113, the corrosion damage under higher intensity cavitation should refer to total damage and not to rate of damage. Final text has been corrected to reflect this.

**Questions by Charles F. Warnock, Meme Grande Oil Co., Apartado 234, Maracaibo, Venezuela:**

1. Were any tests made to determine critical speeds where cavitation took place or was eliminated?

2. Were cylindrical test blades electrically isolated from remaining apparatus such that cathodic currents were collected only by the test specimens thus assuring a current density of 500 ma/sq ft on the test specimens?

**Replies by the Authors:**

In answer to C. F. Warnock's questions, we submit the following: Several checks were made to determine at what critical speed cavitation would begin. It was determined by hydrophonic means and visual observation in the propeller tunnel that 600 rpm was the minimum speed under which cavitation could be

heard or observed. In the actual experiment, the cylindrical blades were not isolated but sufficient current was provided to produce an average current density of 500 ma/sq ft on all exposed metal parts including the test specimens.

**SUMMARY STATEMENTS  
BY AUTHORS**

We are gratified to have received such a large response to our paper from our colleagues and associates working in the area of cavitation damage. Although the results are quite preliminary, and some hypothetical explanation is required to develop a plausible mechanism for cavitation damage and its prevention by electrochemical means, we are confident that as the work is expanded and extended, our views and conclusions will be reinforced. We are glad to know that many of the discussers are in general agreement with our approach, and it is our sincere hope that we can convert those whose skepticism is justified, by a rash of new supporting evidence.

**Any discussion of this article not published above  
will appear in June, 1962 issue**



# The Low Potential Zinc Anode In Theory and Application\*

By J. R. WELLINGTON

## Introduction

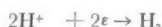
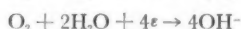
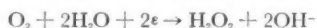
THE ADVANTAGES and disadvantages of galvanic anode materials for cathodic protection can be reasonably discussed only in terms of some specific cathode requirement. For convenience the example used throughout the following discussion is the cathodic protection of the most common structural material, iron and steel, in sea water, (a homogeneous, low-resistivity electrolyte). However, the conclusions derived may be applied to other electrolytes of higher resistivity and to metals other than iron having the same general cathodic polarization characteristics. Since it is the objective of this paper to discuss anode properties and design in terms of cathode requirements, it is desirable first to review briefly the basic principles of cathodic protection.

## Principles of Cathodic Protection

When a metal surface is immersed in an electrolyte such as sea water, differences in potential develop on the surface because some areas are slightly more active than others. This potential difference causes a current to flow through the metal from the less active area to the more active area. Where the current leaves the metal at the more active area, called the anode, metal ions are formed:



That is, the metal corrodes. Where the current enters the metal at the less active or more noble area, called the cathode, oxygen (if available) is reduced or hydrogen gas is formed by the reduction of hydrogen ions as indicated below:



The complete current path for a galvanic cell is for the current to flow through the metal and out into the electrolyte at the anode, then through the electrolyte and back into the metal at the cathode. Now since the current flowing in all parts of the circuit must be the same, and since current flow from metal to electrolyte and vice-versa can only be by the formation or discharge of ions at the surface of the metal, the anodic and cathodic reactions must always proceed at exactly the same rate. If the flow of

current is restricted by the reaction rate at either the anode or the cathode (due to the limited availability of reducible ions, for instance) or by the electrical resistance of the circuit then the flow of current in the cell is said to be under anodic, cathodic or resistance control.

Each anodic and cathodic reaction has its own unique potential, which may be shifted in one direction or another by the presence (or absence) of other chemical species, and which is a function of the reaction rate. Anodic and cathodic reaction rates and potentials can be represented graphically by an Evans polarization diagram, as in Figure 1. This diagram is simply a graph of reaction potential, vs reaction rate (current flow) and shows how the potential of the anodic and cathodic reactions change as the rate of flow of current changes. A change in potential with a change in rate is called polarization. Anode reactions always polarize in the cathodic direction, whereas cathode reactions polarize in the anodic direction.

In Figure 1 the potential of a freely corroding metal surface is represented by  $E_0$ , the intersection of the local anodic and cathodic polarization curves, and the local action current by  $I_0$ . Application of an external current will cause the local cathodes to polarize in the anodic direction as shown. That is, if an external current equivalent to  $I_0 - I_1$  is applied the potential of the metal surface will shift to  $E_1$  and the local corrosion current will be reduced to  $I_1$ . If sufficient external current,  $I_2$ , is applied to polarize the potential of the local cathodes to the potential of the local anodes,  $E_c - E_a = 0$ , no local action current flows and the prevention of further metal dissolution, or corrosion, by cathodic protection has been achieved.

Several interesting things happen at a cathodically protected surface. By holding the potential of the metal surface sufficiently depressed, that is, negatively charged, the escape of positively charged metal ions from the metal surface into the electrolyte is rendered difficult or impossible. Or in other words, metal dissolution is prevented. Also, it should be noted that all of the cathode reactions listed above cause an increase in pH at the metal surface. This is beneficial in the case of an iron cathode, but may cause amphoteric metals such as aluminum and lead to corrode. Another important practical result of cathodic protection, especially in the case of sea water, is that an increase in pH at the cathode surface causes the deposition of films or catenaceous coatings on the metal surface which impede the diffusion of oxygen, reduce cathode current demand, and under some



About  
the  
Author

J. R. WELLINGTON is a research engineer with the Metal Use Research group, Research and Development Division of The Consolidated Mining and Smelting Company of Canada Limited at Trail, B. C. He graduated in 1942 with a BSc in Chemical Engineering from the University of Saskatchewan and, after a period of service in Europe with the Canadian Army, joined Cominco in 1945. Mr. Wellington was for some time in charge of the mitigation of in-plant corrosion problems. Since 1955 he has been associated with the company's metal use research activities, specializing in corrosion studies and new product development. Mr. Wellington is a member of the NACE and is active in the work of ASTM Committee A-5 (Corrosion of Iron and Steel) and B-3 (Corrosion of Non-Ferrous Metals and Alloys).

## Abstract

After a brief discussion of the principles of cathodic protection and the basic requirements of a galvanic anode, anode requirements are examined specifically in terms of the cathodic protection of iron or steel in an electrolyte of uniform characteristics.

For sea water it is shown that it is desirable to limit the cathode polarization to a value less anodic than  $-1.1$  v (vs Ag/AgCl). The advantages of a low potential anode for the cathodic protection of iron under these conditions are discussed in detail in terms of circuit resistance, self-regulation, and current distribution on the cathode. Other desirable anode characteristics such as current efficiency, current capacity per unit volume, and the effect of anode shape on anode current output are examined mathematically. The practical advantages and implications of the above considerations are described. It is suggested that where cathode polarization controls current distribution on the cathode and regulates anode current output, a new concept can be advanced for the design of cathodic protection systems utilizing low potential zinc anodes. 5.2.2

circumstances promote more favorable distribution of current on the cathode.

The source of the external, protective current referred to above can be either impressed, that is, rectified AC or specially generated DC, or galvanic. All things being equal the selection of the best source of protective current is usually based on economic factors. It is the purpose of this paper to describe the very real technological advantages of the low potential galvanic anode and to show how proper design can make use of these advantages and extend the range of usefulness of zinc anodes for cathodic protection.

## Desirable Anode Properties

The most important factor to be considered in the selection of a galvanic anode is the question of solution potential. First of all, the solution potential of the chosen anode material must obviously be more anodic than the potential of the

\* Submitted for publication June 24, 1961. A paper presented at the 17th Annual Conference, National Association of Corrosion Engineers, Buffalo, New York, March 13-17, 1961.



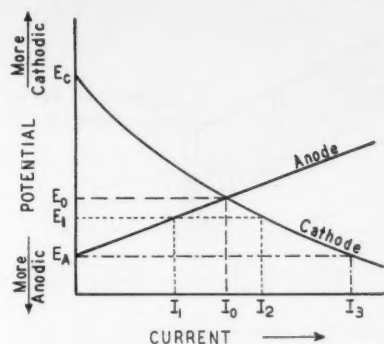


Figure 1—Typical anode and cathode polarization curves.

TABLE 1—Galvanic Series in Sea Water<sup>3</sup>

ANODIC or LESS NOBLE	Magnesium Magnesium Alloys Zinc Aluminum 2S Cadmium Aluminum 17S Mild Steel Cast Iron Lead Brass Copper Stainless Steel	CATHODIC or MORE NOBLE
-------------------------	--	---------------------------

protected cathode surface. Secondly, the solution potential of the material must be stable and reproducible in the environment in which the anode will be used (that is, the material must remain anodic to the cathode throughout the life of the anode and over reasonable changes in current demand). Thirdly, in the case of the iron or steel cathode, or any cathode surface having similar characteristics, the solution potential of the chosen material should desirably be less anodic than a specified maximum permissible cathode potential. This requirement is less obvious than the first two, but it is of great practical importance. Other factors to be considered, which are discussed later, are anode current capacity and current efficiency.

### 1. The Solution Potential of the Anode Material must be more Anodic than the Minimum Protected Potential of the Cathode.

This is an obvious requirement for complete protection. It is mentioned here simply because whenever a metal other than iron is to be protected, galvanic materials other than magnesium, zinc and aluminum ought to be considered. For instance, Sir Humphrey Davy<sup>1</sup> first reported on the use of galvanic iron anodes to protect copper in sea water. Then again, in the plants of The Consolidated Mining and Smelting Company of Canada Limited at Trail, B. C., there is a rather unique application in which galvanic lead anodes are used to protect copper in a hydrofluosilicic acid electrolyte. In selecting a suitable anode material, reference may be made to a Galvanic Series.

The Galvanic Series shown in Table 1, differs from the conventional Electromotive Series in that it lists the metals and alloys in the order of their solution poten-

tials when exposed in a particular environment (sea water in the case shown). These solution potentials are quite reproducible and are simply indicative of the steady state, irreversible reactions proceeding at the metal surface. It will be noted that the general arrangement of the Galvanic Series is much the same as the Electromotive Series but with some important differences.

The solution potential of a zinc anode in sea water is about  $-1.05$  volts, relative to the Ag/AgCl electrode.<sup>(1)</sup> Experience has shown that iron polarized to  $-0.80$  volt is cathodically protected from corrosion. Hence a zinc anode coupled to a protected iron cathode in sea water has an effective driving potential of  $0.25$  volt.

### 2. The Chosen Anode Material must be Capable of Reliable and Efficient Performance as an Anode.

In practice this means that the composition of the anode material must be so controlled and adjusted that the solution potential of the anode does not change with time nor with changes in current demand. In other words, the anode must be capable of delivering the protective current required by the cathode as required.

It is not the purpose of this paper to discuss the importance or the effect of composition on zinc anode performance. Suffice to say that a great deal of research has gone into this subject in recent years and that it has been conclusively demonstrated, especially in the case of sea water, that zinc anodes of controlled and proper composition remain active and do not change potential with the passage of time, and show minimum polarization with changes in anode current density. For detailed results the work of Teel and Anderson,<sup>3</sup> Crennell and Wheeler,<sup>4,5</sup> Reichard and Lennox,<sup>6</sup> Carson, Phillips and Wellington,<sup>7</sup> Waldron and Peterson,<sup>8</sup> and Seo and Take-shima,<sup>9</sup> should be consulted.

### 3. The Solution Potential of the Anode Material should be Less Anodic than a Specified Maximum Permissible Cathode Potential.

It is found desirable in practice to limit the maximum cathode potential to a figure not much greater than the minimum protected potential of the cathode, from which it follows that a low potential (difference) galvanic anode is to be desired. The several reasons why this is so are described below in detail, but all are derived from a consideration of the basic shape and nature of the cathodic polarization curve for iron as shown in Figure 2. As explained by Stern,<sup>10</sup> this curve is the summation of two individual cathode reactions. The first reaction is the reduction of oxygen and the steep portion of the curve represents the limiting diffusion current for oxygen under a given set of conditions. Note especially that once the limiting diffusion current for oxygen is reached a small change in current results in a large change in cathode potential. This portion of the curve

will be displaced to the right or to the left with an increase or decrease in the availability of oxygen at the cathode surface.

The second reaction is the reduction of hydrogen ions to form hydrogen. Note that if the potential of the cathode is held at a value more noble than the activation potential for the reduction of hydrogen ions then the only current consuming reaction that can take place on the cathode surface is the reduction of oxygen. That is, the availability of oxygen at the cathode surface will restrict the flow of current to the cathode and the overall anode-cathode reaction may be said to be under cathodic control. The detailed implications of the shape of this curve and of the reactions represented by the curve on the selection of anode solution potential are as follows:

(a) Since an iron cathode is protected from corrosion at a potential of  $-0.80$  volt, a cathode potential more negative than this is wasteful of current. However, not much current is wasted until the iron cathode is made more negative than  $-1.1$  volts. At potentials more negative than  $-1.1$  volts hydrogen is evolved in quantity and the iron cathode will accept an almost unlimited amount of current with little further change in potential.

(b) Exceeding the hydrogen activation potential, in addition to causing hydrogen evolution, leads to a further increase in pH at the cathode surface as a result of the removal of hydrogen ions from solution. These two effects, either singly or in combination, generally cause rapid and drastic failure of any paint film on the surface of the cathode. Since a protective coating on the cathode surface may be necessary to limit the cathode current demand to a reasonable figure (or for some other purpose, e.g., anti-fouling) paint film failure can result in a large increase in current, often far in excess of the capacity of the cathodic protection system to supply.

(c) If the potential of the iron surface is maintained at a value less negative than  $-1.1$  volts, then the reduction (of significant quantities) of hydrogen ion on the cathode surface cannot occur and the only current consuming reaction possible is the reduction of oxygen. That is, the maximum amount of current that the cathode surface or any part thereof can accept, no matter how short the electrolyte path (how low the resistance) between the anode and the cathode, is equivalent to the limiting diffusion current for oxygen. Conversely, current distribution on the cathode surface will be controlled by the availability of oxygen at the surface and where oxygen is uniformly available current distribution will be uniform, up to some maximum distance beyond which the available driving potential can no longer supply a current density equivalent to the limiting diffusion current for oxygen.

The experimental validity of the role of oxygen in limiting cathode current consumption and controlling cathode current distribution for a low potential anode is shown by the work of Nelson and Waldron.<sup>11</sup> As shown in Figure 3,

<sup>(1)</sup> Note: All potentials referred to in this paper are relative to the Ag/AgCl electrode.



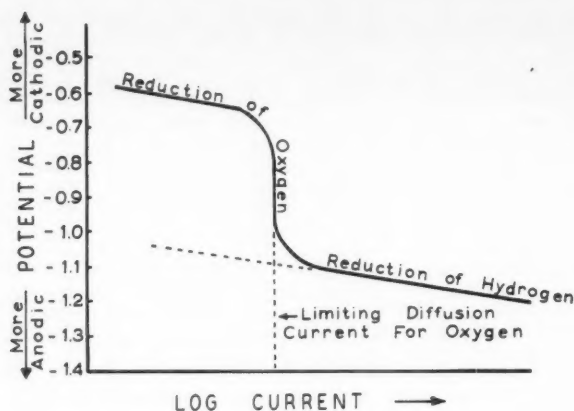


Figure 2—Typical cathodic polarization curve for iron.

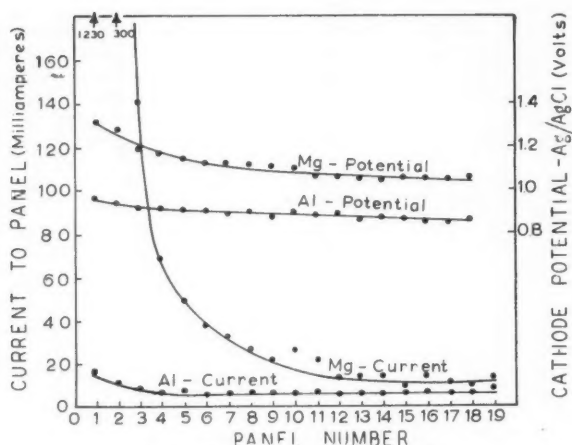


Figure 4—Current distribution from anodes.

Nelson and Waldron placed a segmented steel cathode in a wooden tank 10 ft long by 3 ft wide by 2 ft deep filled with 20 ohm-cm sodium chloride solution. Provision was made for measuring the current to each panel when the cathode was directly coupled to a magnesium or aluminum anode. The results of the test are shown in Figure 4. The aluminum anode which like zinc is a low potential anode, produced a total of 137 milliamperes and polarized all parts of the steel cathode to a protected potential. Using an average figure of 7 milliamperes per panel to polarize to  $-0.85$  volt, the authors calculate that a minimum of 133 milliamperes would be required to polarize the entire cathode if current distribution on the cathode were completely uniform. That is, the low potential anode produced only 3 percent more current than was actually required. The current output of the magnesium anode to the same cathode was 2200 milliamperes.

For the above reasons it is desirable to limit the potential of the cathode surface to the range  $-0.8$  to  $-1.1$  volts. Within this potential bracket it is desirable to have available as large a driving potential as possible. Zinc, with a solution potential of  $-1.05$  volts is ideally

suited for use as a low potential galvanic anode. Any lower solution potential would mean less driving force and more resistance circuit. These principles are illustrated graphically in Figure 5 but first may be explained in terms of Ohm's law as follows:

The current flowing in a galvanic anode circuit is defined by Equation (1). That is,

$$E_c - E_a = IR_e + IR_m \quad (1)$$

$$= IR \quad (2)$$

where  $E_c$  = the polarized potential of the cathode,  $E_a$  = the polarized potential of the anode,  $R_e$  = the resistance of the electrolyte path,  $R_m$  = the resistance of the metallic path, and  $R = R_e + R_m$ ; hence it follows that for a specific current demand  $I$ ,

if  $E_c - E_a$  is large, as for a high potential anode,  $R$  must be large

if  $E_c - E_a$  is small, as for a low potential anode,  $R$  must be small.

If it is assumed there is only a very small change in  $E_a$  with a change in current demand, Equation (2) may be rewritten.

$$\Delta E_c = \Delta IR \quad (3)$$

from which it follows that as  $I$ , the current demanded by the cathode, changes (due to deterioration of paint, seasonal variations in electrolyte characteristics, changes in velocity, etc.),

if  $R$  is large, a change in  $I$  causes a large change in  $E_c$ .

if  $R$  is small, a change in  $I$  causes a small change in  $E_c$ .

Thus, a desirable characteristic of a low resistance circuit is that it is self regulating.

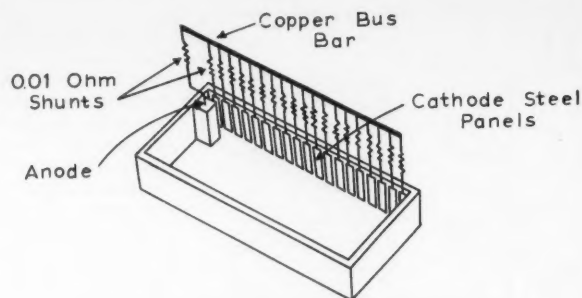


Figure 3—Arrangement of segmented steel cathode.

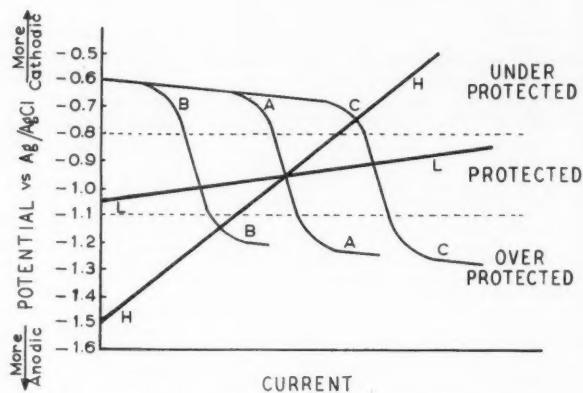


Figure 5—Self-regulating characteristics of low resistance circuit.



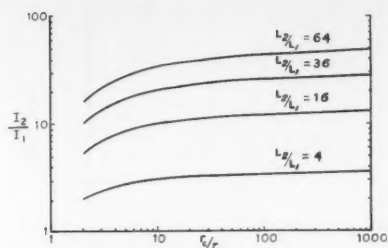


Figure 6—Theoretical current output of cylindrical anodes of various lengths at constant volume.

ulating with regard to current output. As the current required by the cathode changes, the low potential anode responds to the new demand with a minimum change in the potential of the protected cathode surface. As illustrated graphically in Figure 5, where for convenience the IR drop of the circuit is shown as part of the anodic polarization curve, as the cathode current demand (Curve A) increases (Curve C) or decreases (Curve B) the low potential anode (Curve L) maintains the cathode at a safe, protected potential at all times. On the other hand, the high potential anode (Curve H) which must have its circuit resistance designed or adjusted initially to suit Case A, may overprotect if the current demand decreases and will underprotect if the cathode current demand increases.

In summary, a low potential anode, which may be defined as one whose solution potential is less anodic than a specified maximum cathode potential, that is, where

$$E_c \text{ min} > E_a > E_c \text{ max} \quad (4)$$

and, as exemplified by the zinc anode, has the following advantages:

- Minimum wastage of current
- No hydrogen evolution

TABLE 2—Comparative Properties of Galvanic Anodes\*

Property	ANODE		
	Aluminum	Magnesium	Zinc
<b>Theoretical:</b>			
Weight/Volume			
Specific Gravity...	2.77	1.83	7.14
Lbs/cu in. ....	10	0.066	26
Cu in/lb. ....	10.0	15.1	3.88
<b>Electrochemical</b>			
Equivalents			
Amp-hrs/lb. ....	1350	1000	372
Amp-hrs/cu in. ....	135	66	96
<b>Actual:</b>			
Current Efficiency, Percent	54	50	95
<b>Electrochemical</b>			
Equivalents			
Amp-hrs/lb. ....	725	500	353
Amp-hrs/cu in. ....	72.5	31.5	91
Lbs/amp-yr. ....	12.1	17.5	24.8
Cu in/amp-yr. ....	121	264	96
<b>Solution Potential</b>			
vs Ag/AgCl, volts	-1.00	-1.50	-1.05
vs Cu/CuSO <sub>4</sub> , volts	-1.05	-1.55	-1.10
<b>Driving Potential</b>			
To Cathode Polarized			
To -0.80 v (vs Ag/AgCl), volts	0.20	0.70	0.25

\* Typical data for galvanic anodes in sea water, as reported by NACE Task Group T-3G-1. Aluminum anode: Al-5% Zn. Magnesium anode: Mg-6% Al-3% Zn-0.2% Mn. Zinc anode: zinc alloys conforming to MIL-A-18001.

- Uniform current distribution on the cathode
- A low-resistance, self regulating circuit

#### 4. Current Capacity of the Anode Material

It is customary to describe the current capacity of anode materials in terms of ampere-years per unit weight rather than ampere-years per unit volume. However, only under special circumstances is the actual weight of the anode system of critical importance and more attention should be given to the effect of current capacity per unit volume on anode performance. A low current capacity per unit volume means, for a given life, a large, bulky anode. High current capacity per unit volume means, for a given life, a relatively small anode. Small anodes are of substantial advantage in heat exchangers and similar equipment in which the flow of liquid is less impeded and on the hulls of ships on which they produce negligible drag. As will be shown later, high current capacity per unit volume is a desirable property in that it results in a small change in anode surface area per unit of current produced. The smaller the change in anode size per unit of current produced, the smaller the change in anode-to-cathode resistance and the more stable the current output of the anode system.

#### 5. Anodic Current Efficiency

For practical reasons, it is obviously desirable that the current efficiency of the anode material be high. As will be shown later, in order to achieve the low resistance circuit essential to the use of a low potential anode it is necessary to use relatively long, thin anodes with high surface-area-to-volume ratio. For such shapes, a low rate of self corrosion (a high current efficiency) is essential.

#### Design Considerations

Desirable anode properties have been described in terms of solution potential, current capacity and current efficiency, and the advantages of the low potential anode have been examined and discussed

(2) In the discussion to follow, for the sake of brevity, reference is made only to concentric spherical and concentric cylindrical electrode systems where the inner electrode is the anode. However, what applies to a spherical or cylindrical anode also applies to a hemispherical or hemicylindrical anode, or to any other segment of the whole, where division of the anode, electrolyte and cathode is made by an insulating plane or planes. Thus, as a first approximation, an isolated anode fastened to the side of a ship could be considered to be acting as a hemisphere, or a long anode array on a painted sea wall as a hemicylindrical anode.

TABLE 3—Current Output of Spherical and Cylindrical Anodes at Constant Anode Volume, to an Infinitely Remote Cathode

Radius of Anode	Spherical Anode		Cylindrical Anode	
	Number of Anodes	Total Current Output	Length of Anode	Total Current Output
$r$	1	1	L	1
$r/2$	8	41	4L	41
$r/4$	64	161	16L	161
$r/6$	216	361	36L	361
$r/8$	512	641	64L	641

in some detail. That the zinc anode is especially well suited to fill the stipulated requirements is shown in the tabulation of anode properties presented in Table 2. How can these properties best be put to work in practice? The answer to this question is primarily one of anode shape and design.

There are two basic anode shapes: a sphere<sup>(2)</sup> or any blocky chunky shape that could be considered to act like a sphere; and a cylinder<sup>(2)</sup> or any relatively long, thin shape that could act like a cylinder. In actual practice many variations in shape and geometry are possible, but consideration of the characteristics of the two basic shapes, spheres and cylinders, will clearly indicate the preferred anode shape. Anode shape or design is important because it controls the anode-to-cathode or system resistance through its effect on the length and cross-section, and thus resistance, of the electrolyte path.

The basic equations for the resistance, R, of the electrolyte paths for concentric spherical electrodes and concentric cylindrical electrodes are, as reported by Shepard and Graessner.<sup>12</sup>

#### Spheres

$$R = \frac{\rho}{4\pi} \left( \frac{1}{r_a} - \frac{1}{r_c} \right) \quad (5)$$

#### Cylinders

$$R = \frac{\rho}{2\pi L} \ln \frac{r_c}{r_a} \quad (6)$$

where  $\rho$  is the resistivity of the electrolyte (assumed to be homogeneous and infinitely large),  $r_a$  and  $r_c$  are the anode and cathode radii respectively, and L is the anode/cathode length. From these two basic formulae, together with Ohm's law and the appropriate equations for anode volume, a number of interesting conclusions regarding the effect of anode design on anode current output and operating characteristics can be derived.

#### 1. Theoretical Current Output of Spherical and Cylindrical Anodes at Constant Anode Volume

The first question is to examine the current output capability of the two basic shapes with a view to determining which is the preferred shape for a low potential anode. With only low driving voltage available the problem, in the simplest terms, is essentially one of determining which shape offers in some practically obtainable anode arrangement the necessary low, anode-to-cathode resistance.



The initial step in the layout of any galvanic anode system is to estimate the current  $I$  required to protect the structure for the desired number of years  $t$ , and then to calculate the volume of anode material required, which is the electrochemical equivalent of  $I \times t$  ampere-years. The next step is simply to divide up or stretch out this volume of anode material so that it is capable of producing the current  $I$  under the required conditions. The problem then is to rearrange Equations (5) and (6) to show how, at constant anode volume, the current output of a spherical anode system is increased by subdivision of the original volume into smaller spheres, and how, in the case of a cylindrical anode system, the current output can be increased by increasing the anode length with appropriate reduction in anode diameter.

For concentric spherical electrodes, assuming an infinitely large cathode, it follows from Equation (5) that

$$I_1 = \frac{4\pi E}{\rho} r_1 \quad (7)$$

$$I_2 = n \frac{4\pi E}{\rho} r_2 \quad (8)$$

where  $I_1$  is the current output of a sphere of radius  $r_1$ ,  $I_2$  is the current output of  $n$  spheres of radius  $r_2$  and  $E$  is the driving voltage. Now at constant anode volume, that is, where  $V_1 = nV_2$  then

$$\frac{I_2}{I_1} = n^{2/3} \quad (9)$$

For concentric cylindrical electrodes, assuming that the anode and cathode are always of equal length, it can be shown from Equation (6) that

$$\frac{I_2}{I_1} = \frac{L_2 \ln(r_c/r_{a1})}{L_1 \ln(r_c/r_{a2})} \quad (10)$$

where  $I_1$  is the current output of an anode of radius  $r_{a1}$  and length  $L_1$  to a cathode of radius  $r_c$  and length  $L_1$ , and  $I_2$  is the current output of an anode of radius  $r_{a2}$  and length  $L_2$  to a cathode of radius  $r_c$  and length  $L_2$ .

At constant anode volume, where  $V_1 = V_2$  then

$$\frac{I_2}{I_1} \frac{L_2}{L_1} = \frac{1}{1 + \frac{\ln(L_2/L_1)}{2\ln(r_c/r_{a1})}} \quad (11)$$

or

$$\frac{I_2}{I_1} = \frac{L_2}{L_1} \text{ where } r_c = \infty \quad (12)$$

The above calculations ignore interference effects, end effects, etc. But the difference in the two anode geometries, as tabulated in Table 3 shows, for the case of an infinitely large cathode, that the current output of a cylindrical anode is increased 64 times if the anode length is increased 64 times and the diameter reduced proportionately (to  $1/8$ ). To obtain a similar increase in current output from a spherical anode system would require subdivision of the original volume into 512 spheres. Clearly it would take far less effort to dispose of an anode system only 64 units long than of more than 500 individual spherical anodes.

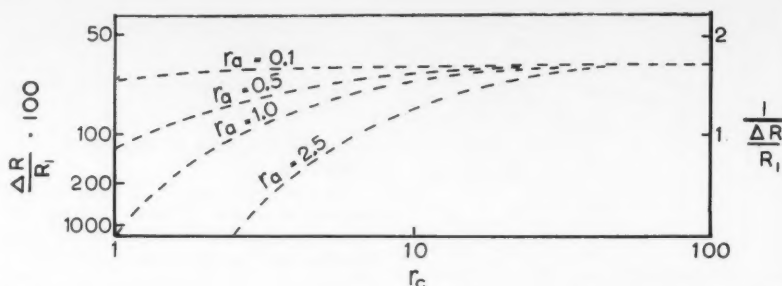


Figure 7—Change in electrolyte path resistance for spherical anodes with 75 percent decrease in volume ( $V_1 = 4V_2$ ).

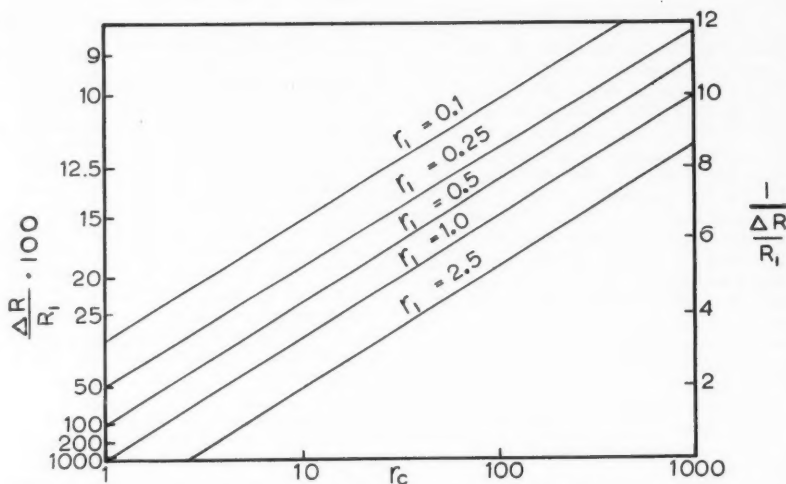


Figure 8—Change in electrolyte path resistance for cylindrical anodes with 75 percent decrease in volume ( $V_1 = 4V_2$ ).

Re-examination of Equation (11), which is plotted graphically in Figure 6, will confirm that for an infinitely large cathode an increase in length of a cylindrical anode shape at constant volume results in a proportionate increase in current output. Even for the practical case where cathode diameter is say 100 times anode diameter the penalty for the resulting decrease in anode diameter is small. In practice, doubling the length of a relatively short cylindrical anode will not, of course, double the current output because of the contribution of end effects. However, the important point is that with relatively long cylindrical anodes or anode arrays, because the resistance to remote earth of the anode is inversely proportional to the length of the anode and is only slightly increased by a marked decrease in anode diameter, one can, for the same volume of anode material, increase the current output by increasing the length of the anode. It therefore becomes possible to choose independently the desired anode life, which is proportional to anode volume, and anode current output, which is proportional to anode length.

## 2. Effect of Decreasing Size on Electrolyte Path Resistance for Spherical and Cylindrical Anodes

A desirable characteristic of any chosen

anode material and shape would be that a decrease in anode size, as a result of anode dissolution would result in minimum increase in resistance of the electrolyte path. Thus, as noted under 4 in the preceding section, the current capacity per unit volume of the anode material is an important factor. Zinc, as shown in Table 2 has the highest current capacity per unit volume of any commercially available anode material. A high current capacity per unit volume means, for each ampere-year of protection delivered to the cathode, the zinc anode system will show only a small decrease in anode size and corresponding small increase in anode-to-cathode resistance. The effect of anode shape on the increase in anode-to-cathode resistance with dissolution of anode material is of critical importance because the major portion of the electrolyte path resistance is in the area of highest current density close to the anode.

For concentric spherical electrodes, by rewriting Equation (5) it can be shown that the change in resistance of the electrolyte path as the anode decreases in size is:

$$\frac{R_2 - R_1}{R_1} = \frac{\Delta R}{R_1} = \left[ \frac{r_1}{r_2} - 1 \right] \left[ \frac{r_c}{r_c - r_1} \right] \quad (13)$$

where  $R_1$  and  $R_2$  are the resistance of the electrolyte paths for anodes of radii  $r_1$



and  $r_2$  respectively. Substituting for  $r_1/r_2$ ,

$$\frac{\Delta R}{R_1} = \left[ \left( \frac{V_1}{V_2} \right)^{1/3} - 1 \right] \left[ \frac{r_c}{r_c - r_1} \right] \quad (14)$$

and for the special case where  $V_1/V_2 = 4$ , that is, 75 percent of the anode is dissolved,

$$\frac{\Delta R}{R_1} = 0.587 \frac{r_c}{r_c - r_1} \quad (15)$$

which is plotted graphically in Figure 7. Equation 15 and Figure 7 show that  $\frac{\Delta R}{R_1}$

will be a minimum for the case where  $r_c = \infty$ , and that the percentage increase in resistance of the electrolyte path, for  $r_c = \infty$ , is independent of the initial anode size and approaches a minimum value of 58.7 percent.

For concentric cylindrical electrodes, by rewriting Equation (6) it can be shown that the change in resistance to the electrolyte path as the anode decreases in radius and where  $L$  remains constant is:

$$\frac{R_2 - R_1}{R_1} = \frac{\Delta R}{R_1} \frac{\ln(r_1/r_2)}{\ln(r_c/r_1)} \quad (16)$$

where  $R_1$  and  $R_2$  are the resistances of the electrolyte paths of anodes of radii  $r_1$  and  $r_2$  respectively. Substituting for  $r_1/r_2$ ,

$$\frac{\Delta R}{R_1} = \frac{\ln(V_1/V_2)}{2 \ln(r_c/r_1)} \quad (17)$$

and for the special case where  $V_1/V_2 = 4$ , that is, 75 percent of the anode is dissolved,

$$\log r_c = \frac{0.301}{\Delta R/R_1} + \log r_1 \quad (18)$$

for which a family of straight lines may be drawn as shown in Figure 8. Equation (17) and Figure 8 show that, for a cylindrical anode of fixed length, the increase in resistance of the electrolyte path with a decrease in anode diameter,

- (1) Is dependent on the ratio  $r_c/r_1$ ;
- (2) Approaches 0 as  $r_c/r_1$  approaches  $\infty$ ;
- (3) Is reduced, for a fixed value of  $r_c$ , as the initial anode size  $r_1$  is reduced;
- (4) Is, within practical limits and for 75 percent reduction in anode volume, 10-25 percent.

In summary, it has been shown that the increase in resistance of the electrolyte path, for 75 percent dissolution of the anode, is 60 percent or more for spherical anodes and 10 to 25 percent for cylindrical anodes. Thus, a cylindrical anode is to be preferred to a spherical anode because the change in resistance as the anode metal dissolves is less and the capability of the cylindrical anode to put out current, as it nears the end of its useful life, is not unduly decreased.

### 3. Practical Design Considerations

The preceding discussion has indicated that a low potential anode must be relatively long and small in cross-section in

order to be useful. Such shapes provide minimum anode-to-cathode resistance (per unit volume of anode material), and minimum change in resistance with anode dissolution; also they take advantage of zinc's high current efficiency. That is, wherever the anode is a relatively long, thin shape with high surface-area-to-volume ratio, then it is important that the rate of self corrosion to the anode material be low. Fortunately, for zinc, this is so.

In passing it might also be noted that an important practical requirement for an anode material is that it be easily fabricated into all the various forms and shapes in which the anode may be required. Again, with zinc, this is so.

A very practical advantage of the low potential anode is that it can be affixed directly to the cathode surface. As pointed out under 3(c) in the preceding section, with a low potential anode the maximum current density on any part of the cathode surface is determined by the limiting diffusion current for oxygen. Thus the current density on the cathode surface immediately adjacent to the anode will be essentially the same as the current density at some distance from the anode, depending on the exact slope of the cathodic polarization curve. There is, therefore, no wastage or excessive dissolution of anode metal immediately adjacent to or in contact with the cathode surface. This point is of course of great practical importance in that direct mounting of a zinc anode on the cathode is simple, rugged, foolproof and inexpensive. No special shielding of the anode or cathode, supporting brackets, or of copper lead wires is required.

It will be readily appreciated that the properties and characteristics of the low potential zinc anode as described above go a long way towards solving the corrosion engineer's cathodic protection problems. As desirable as these advantages may be, in the final analysis, the choice of cathodic protection systems, of anode material, will be based very largely on cost. It is therefore important that cost comparisons between systems be on a proper basis, which is the unit of protection, the ampere-year. Figure 9 is designed to show, for the common galvanic anode metals, the cost in terms of \$/ampere-year if the cost in \$/lb of anode metal, or more properly, of anode metal installed, is known. Similarly, the cost of impressed current systems, for installation, amortization, maintenance and operation can be expressed in terms of \$/ampere-year. However, whenever a cost per ampere-year comparison is made it should be borne in mind, especially when the cathode current requirement is only estimated, that the low potential zinc anode will never put out more current than the cathode actually requires and that all of the current produced will be used at maximum efficiency.

### Summary

From the foregoing discussion it is clear that the design of cathodic protection systems based on low potential zinc anodes is greatly simplified due to the inherent self-regulating characteristic of

the low potential anode. With a high potential anode it is desirable to neither underdesign nor overdesign. With a low potential anode the designer need concentrate only on avoiding underdesign through the use of a suitably low resistance circuit. A low resistance circuit is readily attainable in a practical, efficient and economical manner by the use of relatively long, thin cylindrical anodes and anode arrays. Because the anode/cathode resistance of a cylindrical anode is inversely proportional to anode length and is little affected by changes in diameter, a preselected volume of anode material can be adjusted in length to give any desired anode/cathode resistance. The lower the anode/cathode resistance, the greater the capability of the system to produce current. However, due to the self regulating property of the low potential anode, the system will produce only the current actually required by the cathode. It is entirely feasible, therefore, in the design of cathodic protection systems utilizing low potential zinc anodes in the form of long cylindrical arrays, independently to select anode life and anode current output. If a large current is required a long anode is used; if a short life is desired an anode of small cross-section is used.

This flexibility in design can be further used to advantage in the following manner: there is a tendency to overestimate cathode current requirements in the design of cathodic protection systems in order to guard against underdesign. Here the low potential zinc anode offers a two-fold advantage: When calculating the volume of anode metal required, use the average or minimum estimated current demand; when calculating anode length, use the maximum estimated current demand. This procedure will result in the design of a system that has the capability of supplying the maximum cathode current requirement when required, and at the same time will result in the installation of the minimum quantity of anode material required to yield the desired life. Advantage also can be taken of the ability of the low potential zinc anode to produce very large currents when working against an unpolarized cathode, to obtain the benefits claimed for "pre-polarization" of the cathode.

In conclusion, it is suggested that a fuller understanding and appreciation of the properties and operating characteristics of low potential zinc anodes will lead to new and simplified methods for the design of anode systems. Much information has been published on the effect of anode spacing and arrangement on cathode current distribution for high potential anodes (galvanic or impressed). In all this work it has been necessary to ignore the role of cathode polarization, because of the difficulties involved in treating the problem mathematically; all calculations have dealt solely with the role of electrolyte resistance in controlling current distribution on the cathode. With the low potential anode the problem is basically quite different. Here cathode polarization alone governs current distribution on the cathode and electrolyte resistance is of interest only



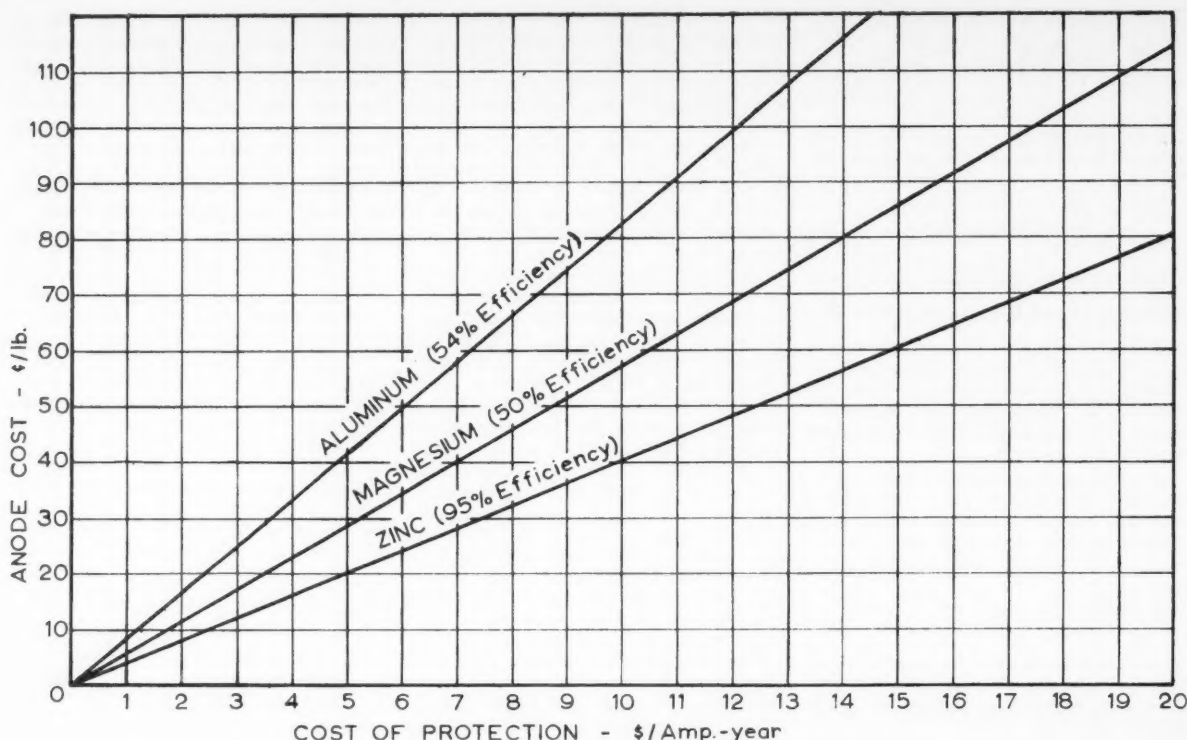


Figure 9—Cost of cathodic protection vs anode cost.

insofar as it limits the maximum distance over which some minimum cathode current density can be delivered. It is believed that an approach along these lines to the design of zinc anode systems will yield interesting and useful results.

#### Acknowledgments

The author wishes to acknowledge the contribution of W. L. M. Phillips, The Consolidated Mining and Smelting Company of Canada Limited, for helpful discussion of the material presented and in the preparation of the manuscript. The permission of The Consolidated Mining and Smelting Company of Canada Limited to publish the information is acknowledged.

#### APPENDIX—Cost of Cathodic Protection—How to Use Figure 9

To compare cost of protection of different anode metals: enter graph on left hand side at cost of anode, expressed in ¢/lb, and below intercept on appropriate line read cost of protection in \$/amp-yr. Example: a zinc anode at 20¢/lb is ≈ \$5.00/amp-yr; a magnesium anode at 50¢/lb is ≈ \$8.75 amp-yr.

To compare cost of protection of different anode systems: to cost of anode

metal delivered at site in ¢/lb add cost of installation expressed in ¢/lb of anode metal. Example: assume that one ampere-year equivalent of zinc or of coated magnesium will protect a heat exchanger for one year and that cost of installation is \$25. Zinc system: cost of anode = 40¢/lb. Cost of installation = \$25.00/24.8 = 101¢/lb, total cost of zinc anode system = 141¢/lb = \$35/amp-yr. Magnesium system: cost of anode = 100¢/lb, cost of installation = \$25.00/17.5 = 143¢/lb, total cost of magnesium anode system = 243¢/lb = \$42.50/amp-yr.

To compare cost of protection of impressed current and galvanic anode systems: express cost of impressed current system in terms of \$/amp-yr (i.e. annual operating and maintenance costs plus allowance for amortization divided by cathode current requirement in amperes = cost of protection in \$/amp-yr). Enter graph at cost of protection, in \$/amp-yr, for impressed current system and opposite intercept on appropriate line read cost of different galvanic anode systems in terms of cost per pound of anode metal installed. Example: estimated cost of impressed current system = \$12/amp-yr which is equivalent to an installed anode cost of 48¢/lb for zinc, 69¢/lb for magnesium and 99¢/lb for aluminum.

#### References

1. H. Davy. Additional Experiments and Observations on the Application of Electrical Combinations to the Preservation of the Copper Sheathing of Ships, and to Other Purposes. *Phil. Trans. Royal Soc.*, 114, 242 (1824) June.
2. F. L. LaQue and G. L. Cox. Some Observations of the Potentials of Metals and Alloys in Sea Water. *Proc. ASTM*, 40, 670 (1940).
3. R. B. Teel and D. B. Anderson. The Effect of Iron on Galvanic Zinc Anodes in Sea Water. *Corrosion*, 12, 343t (1956) July.
4. J. T. Crennell and W. C. G. Wheeler. Zinc Anodes for Use in Sea Water. *Jl. Applied Chemistry*, 6, 415 (1956) Oct.
5. J. T. Crennell and W. C. G. Wheeler. Zinc Alloy Anodes. *Jl. Applied Chemistry*, 8, 571 (1958) Sept.
6. E. C. Reichard and T. J. Lennox, Jr. Shipboard Evaluation of Zinc Galvanic Anodes Showing the Effect of Iron, Aluminum and Cadmium on Anode Performance. *Corrosion*, 13, 410t (1957) June.
7. J. A. H. Carson, W. L. M. Phillips and J. R. Wellington. A Laboratory Evaluation of Zinc Anodes in Sea Water. *Corrosion*, 16, 171t (1960) Apr.
8. L. J. Waldron and M. H. Peterson. The Effect of Iron, Aluminum and Cadmium Additions on the Performance of Zinc Anodes in Sea Water. *Corrosion*, 16, 375t (1960) Aug.
9. Masao Sea and Shinichi Takeshima. Corrosion Prevention in Oil Tankers. *Corrosion Prevention and Control*, 7, 32 (1960) July.
10. M. Stern. Fundamentals of Electrode Processes in Corrosion. *Corrosion*, 13, 775t (1957) November.
11. E. E. Nelson and L. J. Waldron. Effect of Anode Potential on Cathodic Current Efficiency. Navy-Industry Zinc Symposium on Cathodic Protection. Technical Paper No. 6, April 21-22, 1955.
12. E. R. Shepard and H. J. Graesser, Jr. Design of Anode Systems for Cathodic Protection of Underground and Water Submerged Metallic Structures. *Corrosion*, 6, 360 (1950) November.

Any discussion of this article not published above  
will appear in June, 1962 issue



17

It's different! a completely new

## ANODE MATERIAL

# DURICHLOR 51

Developed after years of extensive research for the cathodic protection of piers, off-shore drilling rigs, heater-treaters, or any structure employed in or handling salt, brackish, or high temperature fresh water

### THE RESULTS OF TESTS

DURICHLOR 51 anodes were not released for field trials until after they had passed, with complete satisfaction, extensive laboratory tests in environments known to cause either severe general or localized attack on existing materials. After all laboratory tests had proved favorable, field installations were made to test DURICHLOR 51 under actual operating conditions known to be too severe for existing metallic and non-metallic anodes. There has been no indication of any selective attack in any of the field tests reported; and in general, these tests have substantiated laboratory data. Significantly, in some cases, the DURICHLOR 51 anodes have been in service approximately one year showing no sign of selective attack in applications where other materials have failed in as short a time as two months.

### THE DEVELOPMENT

The introduction of the high silicon iron alloy, DURIRON, as an anode material in 1954 extended the range of application for cathodic protection into areas where it had not previously been economically feasible. There were environments, however, in which neither DURIRON nor the molybdenum containing alloy, Durichlor, were completely satisfactory. Research was begun back in 1954 in the DURCO laboratories. The alloy that showed the most promising results as it progressed through the laboratory had been designated D-51X. When field trials were begun, the material was referred to as DURCO D-51. Now that all test data prove its merit, the material is made commercially available as DURICHLOR 51.

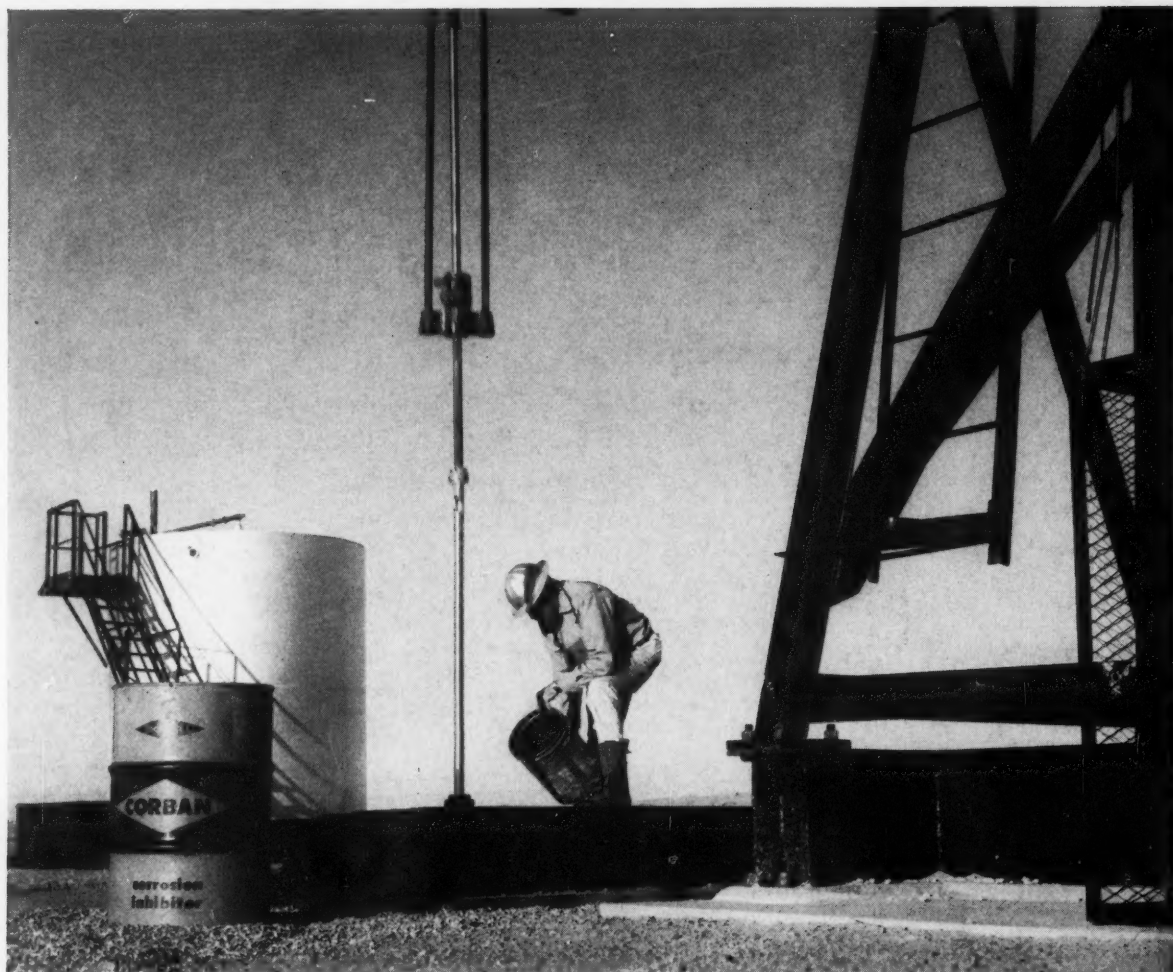
### AREAS OF APPLICATION

DURICHLOR 51 was developed as an anode material for application of impressed current cathodic protection in aggressive salt and brackish waters, high temperature fresh waters, and in chloride containing soils where the chlorine generated at the anode surface was not free to permeate to the surrounding environment. Structures include steel support members for terminals, docks, off-shore drilling rigs and others exposed to sea water; heater-treaters, water box coolers, industrial hot water tanks, and similar fresh water applications; and pipe lines, storage tanks, well casings, and other underground structures.

THE DURIRON COMPANY, INC., DAYTON 1, OHIO







## three ways Corban helps cut secondary recovery costs

Many producers are cutting expenses of secondary recovery projects by using Corban®, Dowell's family of versatile, low-cost corrosion inhibitors. Corban helps reduce costs in three important ways:

**FIRST**, Corban greatly extends the life of tubular goods by retarding corrosion. This holds true for surface lines as well as downhole tubing.

**SECOND**, Corban works two ways to reduce formation plugging. It reduces the formation of insoluble iron salts—a result of corrosion—that is a serious cause of formation plugging. It also acts as a detergent to help disperse organic deposits. In most fields, Corban

helps increase water injection rates and/or decrease injection pressures.

**THIRD**, Corban reduces sucker rod failures caused by corrosion. Sucker rod life has been lengthened dramatically when treatments using Corban were begun.

Corban also helps control corrosion in gas wells, flowing oil wells and salt water disposal projects. Twelve different formulations are available to meet a wide range of well conditions. Ask your Dowell representative for full information. Dowell services and products are offered in North and South America, Europe, North Africa and Iran. Dowell, Tulsa 14, Oklahoma.

PRODUCTS FOR THE OIL & GAS INDUSTRY

**DOWELL**

DIVISION OF THE DOW CHEMICAL COMPANY